University of Puerto Rico at Mayagüez
GEOL 6991-Special Problems in Applied Geology
Introduction to GIS for the Earth Sciences

**Pedestrian Evacuation Model for Mayagüez, PR**

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## Abstract

Recent disasters around the world highlight the threat for coastal communities if a tsunami occurs. Since the initial wave may arrive within minutes it becomes essential that emergency managers understand how much time it could take for a coastal population to reach higher ground before tsunami waves arrive at the moment of developing tsunami-education efforts and vertical-evacuation strategies. This study provide a Tsunami Evacuation model for pedestrians in the area of Mayagüez and aid in the effort of preparing coastal communities by providing the emergency managers with more specific time information not available before. The Pedestrian Evacuation Analyst software used for this work implements an anisotropic path-distance approach specified this time for local tsunami threats. We used a slow walk (1.1 m/s) travel speed evacuation approach and found that only a only a fraction (~3,400) of the total population (24,811) will be able to evacuate within the expected 5 minutes after the tsunami is generated.
This suggests the importance of creating Vertical Evacuation structures within the Tsunami Evacuation Zone since these structures can make a big difference when time is essential to evacuate. A few minutes can represent thousands of saved lives.



Keywords: Tsunami, Evacuation, Pedestrian, Modeling, ArcGIS tool, Mayagüez

## Introduction

Recent disasters around the world highlight the threat for coastal communities in the event of a tsunami. According to Wood and Schmidtlein (2012), after an earthquake or a landslide occur, sudden-onset hazards can arrive within minutes of the event that triggered them as it could be tsunamis or mudslides. They explain that due to the limited amount of time between generation and arrival of sudden-onset hazards, evacuations are typically self-initiated, on foot, and across the landscape.

A tsunami consists of a series of ocean waves that in deep water can travel as fast as 500 miles per hour and as they approach the coast, its speed and the distance between the waves decreases, and the height increases (Mayagüez Map, 2011). Since the initial wave may arrive within minutes and large waves and strong currents may continue to affect the coastal zones for hours (Mayagüez Map, 2011), it becomes essential that emergency managers understand how much time it could take for a coastal population to reach higher ground before tsunami waves arrive at the moment of developing education efforts and vertical-evacuation strategies (Wood and Schmidtlein, 2012).

Wood and Schmidtlein, 2012, explain that in order to calculate the pedestrian evacuation potential of vulnerable communities, researchers use both static least-cost-distance (LCD) and dynamic agent-based models. LCD efforts are focused on an anisotropic (slower travel time uphill vs faster travel time downhill) path distance modeling approach that incorporates travel directionality, multiple travel speed assumptions, and cost surfaces that reflect variations in slope and land cover (Wood and Schmidtlein, 2012).The Pedestrian Evacuation Analyst (PEA) software used for this work implements this anisotropic path-distance approach, specifically designed for pedestrian evacuation from sudden-onset hazards and adapted this time for local tsunami threats (Jones, et al., 2014). According to Jones, et al., 2014, the model estimates evacuation potential based on elevation, direction of movement, land cover, and travel speed and creates a map showing travel times to safety, a time map, throughout a hazard zone.

Our area of study includes the complete coastal area of the Mayagüez municipality, which is located to the west of Puerto Rico. We choose this area mainly because is an area where previous studies has been conducted related to the tsunami hazard but also because there are many people living in the coastal area specified as inundation area in case of a tsunami. According to Von Hillebrandt (2007), the danger zone in case of a tsunami in most of the municipality is found between the coast and the east side of Road #2 as we can see in Fig 1. Census of 1900 reports that they were 20,940 persons, 8464 households and 5,000 families including 1,590 children and 2,390 persons older than 64 years. There are also schools, factories, churches, parks, sport facilities, restaurants and the usual presence of tourists mostly due to the trips of the Ferry from the Mayaguez Port (Von Hillebrandt, C., 2007).

In Fig. 2 we can see the evacuation map created by the Office of Emergency Management and the Puerto Rico Seismic Network for the Mayaguez Area, showing what is considered as the hazard zone, as well as the safe zone. This map was design to help the communities located in the coastal area to identify and reduce the vulnerability in case of inundation caused by tsunami. It presents an inundation zone that was determined for tsunamis generated by local earthquakes, under the worst case scenario (Mayagüez Map, 2011) where is expected people will evacuate the TEZ during the first 5 minutes after the emergency. Since this map does not provide for the time pedestrians will need to evacuate the zone, our work becomes very relevant for this zone.

## Objective

This project is intended to provide a Tsunami Evacuation model for pedestrians in the area of Mayagüez and aid in the effort of preparing coastal communities for the event of a tsunami. To achieve this, we used the ArcGIS-Pedestrian Evacuation Analyst Tool, whose goal is to provide a research tool for exploratory analysis of evacuation potential depending on the landscape. This tool was developed to help investigators studying pedestrian, self-initiated evacuation from sudden-onset hazards, such as local tsunamis, debris flows, lahars and flash floods (Jones, et al., 2014).

## Methodology

The first step was to find and download suitable data for the area of interest, taking into consideration the needs of the software. For the Digital Elevation Model (DEM), for example, the user has the option of entering both DEM raster and vector study-area files or only a DEM raster file. For all the raster files you need to cut and prepare the Tsunami Evacuation Zone (TEZ) for each, specifically for the DEM, roads and land cover and use files.

Table 1 shows the required input files for various pedestrian evacuation analyst processing steps. Once this step is complete we then have to prepare the DEM, the Land use/ Land cover and the Hazard Zone data for input into software. Then we are finally set to run Pedestrian Evacuation Analyst Tool (PEA) within the ArcGIS 10.1 program. Table 2 also gives us a summary of the workflow but for a complete step by step please refer to their paper since for the creation of our project it was the methodology that we used.

The following workflow describes in detail the steps taken, as obtained from Jones, et al., 2014. For our specific analysis there were some steps that were not performed because they didn’t result necessary to the analysis like for example, we did not to define a safe zone because both the hazard and safe zone has been previously determined for the Mayaguez area (Fig. 2). Another step that was not performed was the vertical evacuation analysis because there are no vertical-evacuation structures available within the TEZ for the Mayaguez area.

## Portfolio Management

The workflow begins by creating a portfolio for each study area. Since the PEA tool aids the investigator by simplifying the task of managing the data and results files associated with various processing scenarios, the software uses the portfolio concept to relate files and keep the names associated with processing scenarios, folder paths, and file paths in a database.

## Digital Elevation Model Preprocessing (DEM)

DEM preprocessing identifies the projection and the study area for the scenario and this is the first of the data preprocessing steps. As a requirement of the PEA, all input files have to be in the same projection in order to allow the user to select the proper data transformation for maximum accuracy when converting files from different projections. Fig. 3 shows the DEM processing for the Mayagüez area.

## Land-Cover Preprocessing

In this preprocessing step all inputs are related to land cover in a single layer, using this to create the cost-inverse raster. The tool only requires a base land-cover layer file but you can also choose to add ancillary files like roads, water bodies, buildings or fences so that they can be overlaid on the base land-cover layer. For our specific analysis we used the land cover layer as well as a layer for the roads. In the Fig. 4 we can see the Land use, land cover for the Mayagüez area, as well as for the TEZ. Fig. 5 shows roads for the whole Mayagüez area and roads only within the TEZ zone. This step is important because when entering land-use and land-cover layer, the user sets each unique land-cover type to a specific speed conservation value or enters a custom value speed conservation values that represent the fraction of a maximum speed that could be achieved across the given land cover type. Here, values fall on a spectrum from 0 to 1.0, which means that pedestrian evacuation speed is 100 percent of the base travel rate.

## Hazard-Zone Preprocessing

This tool can be used to create a safe-zone polygons from an input layer of hazard zones and the study area outline as shown in Fig. 1. If a safe-zone layer is already available, this step can be skipped. In this step the hazard zone is erased from the study area to create the safe zone, breaking it into individual polygons to assist in the next step.

## Path-Distance Surface Creation

For this step, the path-distance tool uses as input the previous mentioned preprocessed steps (DEM, least cost-inverse raster, and validated safe zone) to determine travel distance from every cell to the closest safe zone, within the study area. Once the step is completed the target-path distance raster is ready to be multiplied by the travel speed in the next step to determine the travel times to safety.

Evacuation Surface Creation

In this step is where a travel speed is multiplied by the target path-distance raster in order to create the evacuation-time surface map that contains the travel times in minutes to safety. For our analysis we took into account the anisotropic approach that accounts for a slower walk uphill than downhill. Table 3 shows the travel-speed names and corresponding values in the PEA. Fig. 6 shows the path distance surface creation for the TEZ showing path distance to the safety zone in minutes.

Time-Map Generation

Then, finally, a time map generated in minutes is created from the evacuation-time surface by reclassifying the surface into an integer raster at 1-minute increment bands. This raster is then converted to polygons for use in the population analysis.

Population

This tool uses input population data and the processed time map to determine the numbers and types of populations at various travel times to safety. Table 4 shows the Census data that we used for the Mayaguez area from where we created 2 categories (employees and residents) to help analyze possible impact for the population within the TEZ zone. The PEA is designed to count population only within the hazard zone and the minimum expected travel time to safety is 1 minute. Fig. 6 also shows how the population data was integrated to the path distance time.

**Results**

The final tool within the PEA creates graphs that helps visualize the results of the population data in relation to travel times. Graphs in Fig. 7 and 8 shows the time that takes with the slow walk analysis, for the employees or residents, respectively, within the TEZ to evacuate to the safe zone. Fig. 10 shows the time that takes both the employees and the residents within the TEZ to evacuate to the safe zone. The graphs show that approximately 3,400 persons, between residents and employees, will be able to evacuate the safe zone within the first 5 minutes and that close to 150 of residents and close to 250 employees will requires longer times to evacuate, from 15 up to 37 minutes approximately, considering a slow walk scenario of 1.1 m/s. Fig. 11 shows the pedestrian evacuation time map for the Mayagüez area showing time in minutes that would take for pedestrians to arrive to the safe zone. It is shown here that pedestrians closest to the safe zone can take from 0 to 17 minutes and how this time increases with distance, getting to a maximum of 62-98 minutes for the population that is present right in the coast border for some areas.

## Discussion

The model results provide a general view of the evacuation landscape at different pedestrian travel speeds and can be used to identify areas outside the reach of naturally occurring high ground (Jones, et al., 2014).We know that ideal evacuation from the TEZ should be achieved within 5 minutes of the event that might trigger the on-set hazard. In this case, evacuation should be completed within 5 minutes of the earthquake before the tsunami wave arrives. For the purpose of this study, the chosen population categories were employees and residents since this becomes important at the time of taking emergency management decisions related to how much population will be inside the TEZ zone depending on when the emergency might occur.

According to our analysis, which was set for slow walk travel speed evacuation (1.1 m/s), only a fraction of the total population, including both the employees and the residents, will be able to evacuate within the expected 5 minutes. It is important to note that the quantities presented in the graphs do not reflect the total of the population living in the coastal area, which accounts for a total of 24,811 persons. Total time distribution can be better appreciated in pedestrian evacuation time map for the Mayagüez area where we find that some areas could evacuate faster into the safe zone, from 0 to 17 minutes and how this time increases with distance, getting to a maximum of 62-98 minutes for the population that is present right in the coast border for some areas. An important point to take into consideration here is that we are only using the TEZ for the Mayaguez area and not taking into account the DEM of the areas from the municipalities of Añasco or Cabo Rojo which if added to the analysis would have probably yielded closer areas for the population to reach for safe zones and thus, minimize the time to safety in certain areas.

## Conclusion

This study provide a Tsunami Evacuation model for pedestrians in the area of Mayagüez and aid in the effort of preparing coastal communities by providing the emergency managers with more specific time information not available before. By referring to the map, emergency managers can identify better which areas need more attention or will need more assistance in the event of a tsunami. Using the anisotropic approach, the slow travel speed parameter used show that only a fraction of the population within the TEZ will be able to evacuate fast enough. This suggests the importance of creating Vertical evacuation structures within the TEZ since this structures can make the a big difference when time is essential to evacuate, a few minutes less to safety in this case could mean thousands of saved lives. It also suggest the importance of public educational campaigns for tsunami risk reduction strategies that will at least provide the population with the knowledge to identify the danger and react promptly since time is the more essential factor here to be able to reach safety. It is important to note that the pedestrian evacuation tool should be used only to have a general idea for possible scenarios, and these results are intended to initiate risk-reduction and preparedness discussions within communities and not serve as definitive statements on the potential mortality from a determined situation.

## Recommendations

An important recommendation for future work would be the use of more high resolution data since it will provide more accurate travel time speeds calculations. Accurate and updated LULC layers and population data will also provide with a better analysis. If vertical evacuation structures become available within the TEZ it will be essential to run the PEA with the vertical-evacuation analysis step.

## Acknowledgements

Special thanks to Roy Ruiz, GIS Specialist at the Water Resource Institute in UPRM for helping us with the preprocessing steps and providing us with most of the data required to run the ArcGIS Pedestrian Tool.

## Appendix

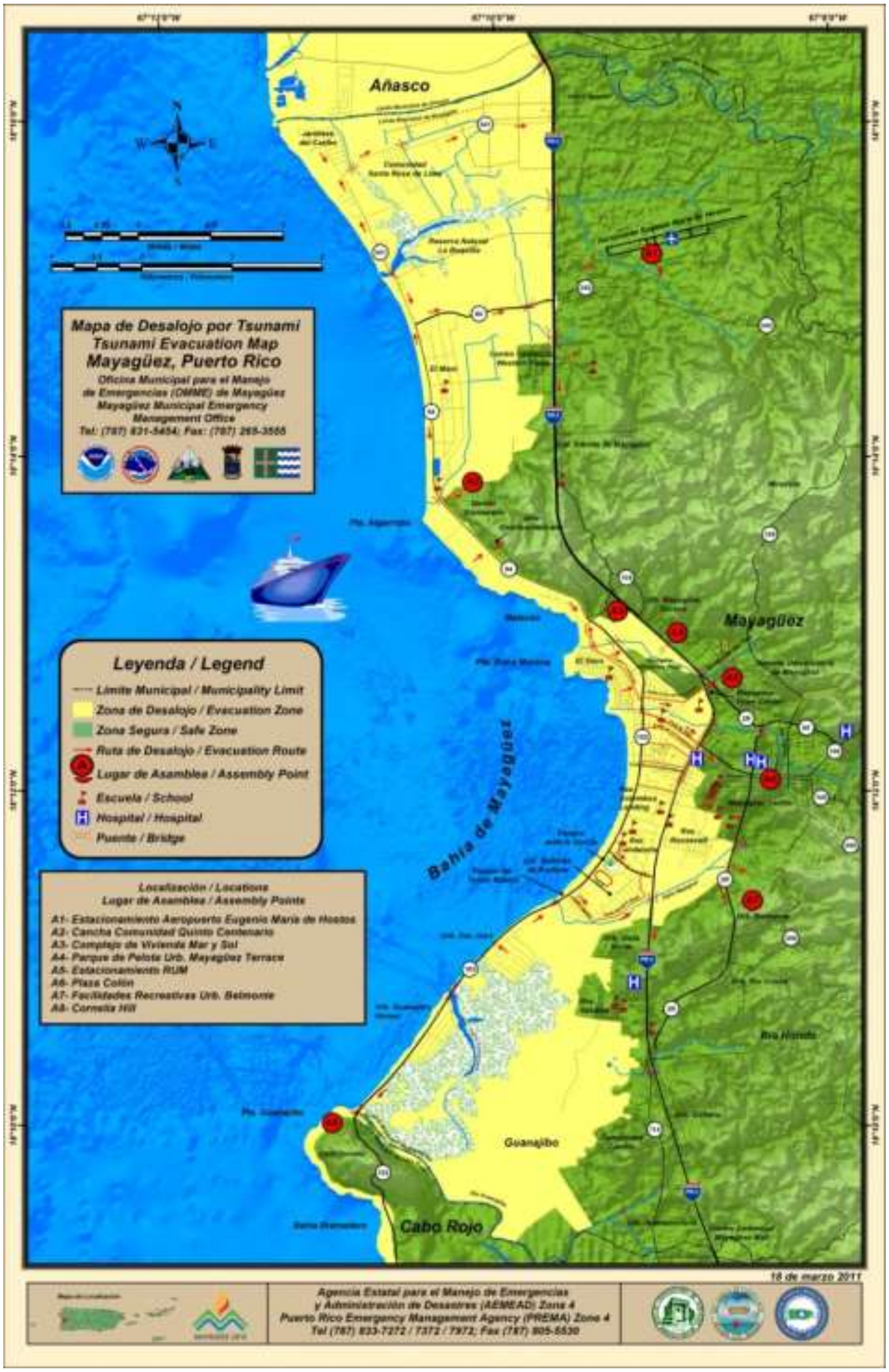
ArcGIS Online WebMap

For the purpose of this study we created an ArcGIS online WebMap where the user can interact with the different layers that compose our analysis for Pedestrian Evacuation within the TEZ for the Mayaguez area.

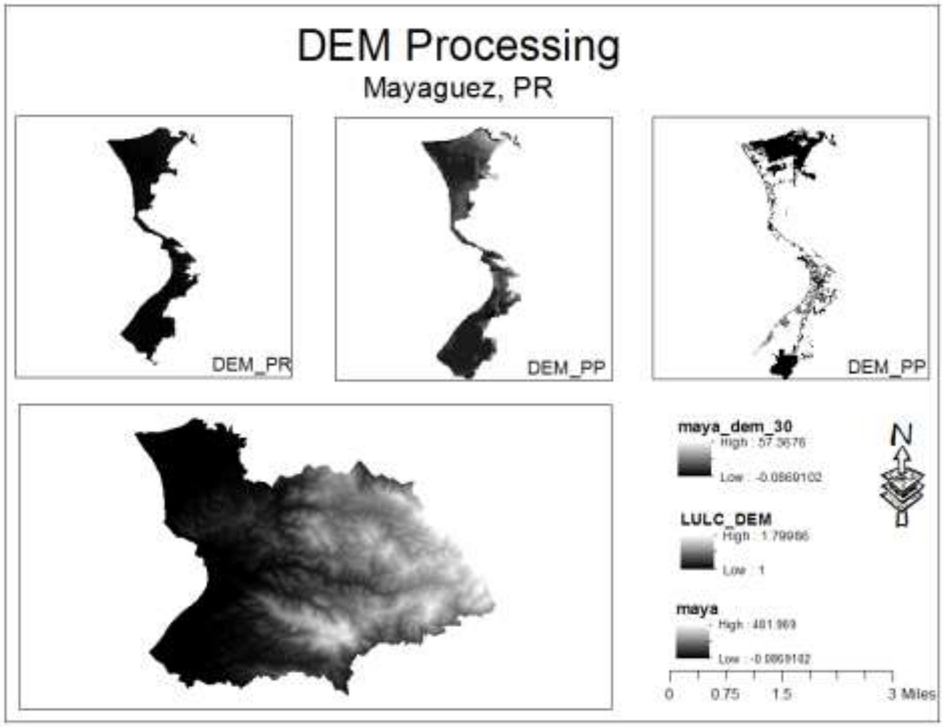
It can be accessed through the following link: http://bit.ly/1vAYNjv.

## Figures

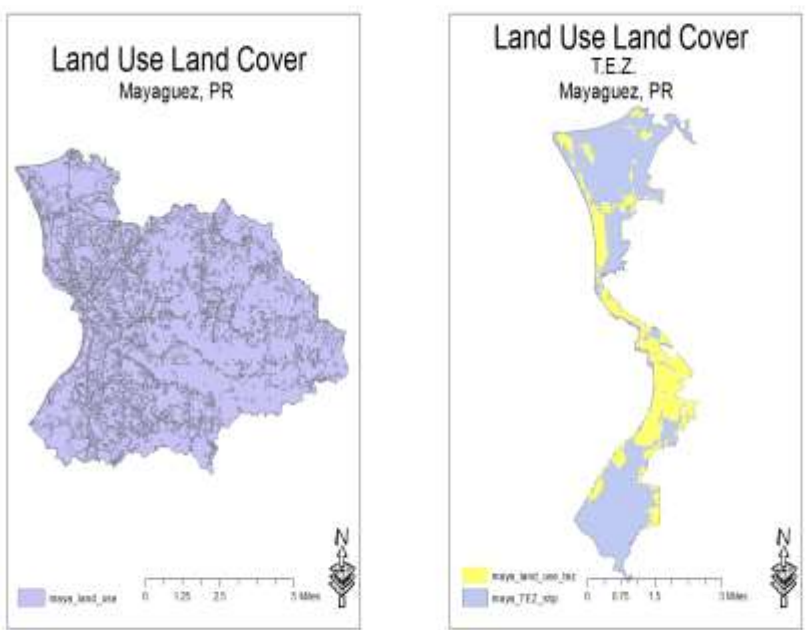

Figure 1 Area of Study. Yellow layer shows potential inundation area for the Mayagüez area.




<u>Figure 2</u> Tsunami Evacuation Map for the Mayagüez Municipality (Mayagüez Map, 2011)




<u>Figure 3</u> Digital Elevation Model processing for the Mayagüez area




<u>Figure 4</u> Land use, land cover for the Mayagüez area and the Tsunami Evacuation Zone

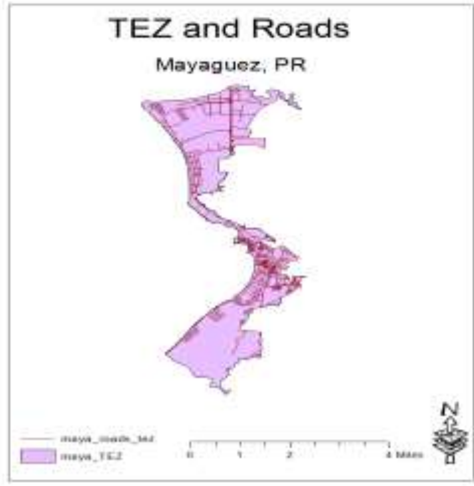




Figure 5 Left map shows roads for the whole Mayagüez area and the map from the right shows roads only within the TEZ zone for the Mayagüez area.

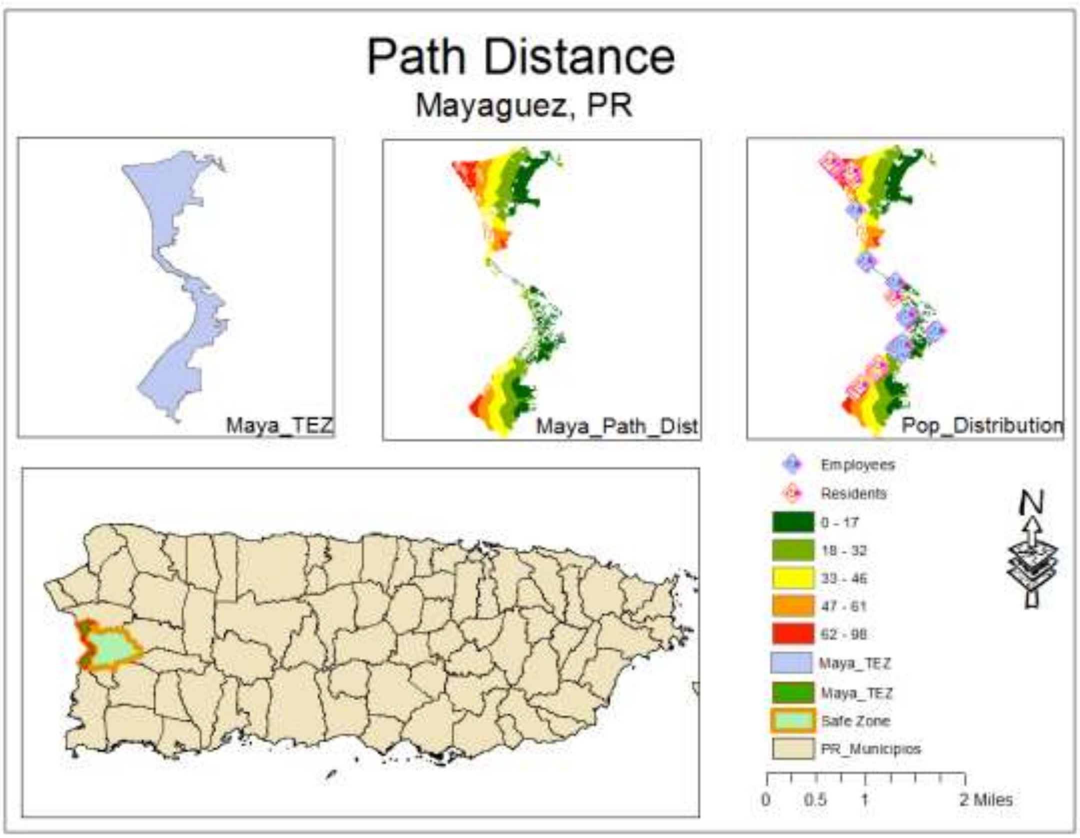



Figure 6 Path distance surface creation for the TEZ showing path distance to the safety zone in minutes and incorporating a Population Distribution for residents and employees.

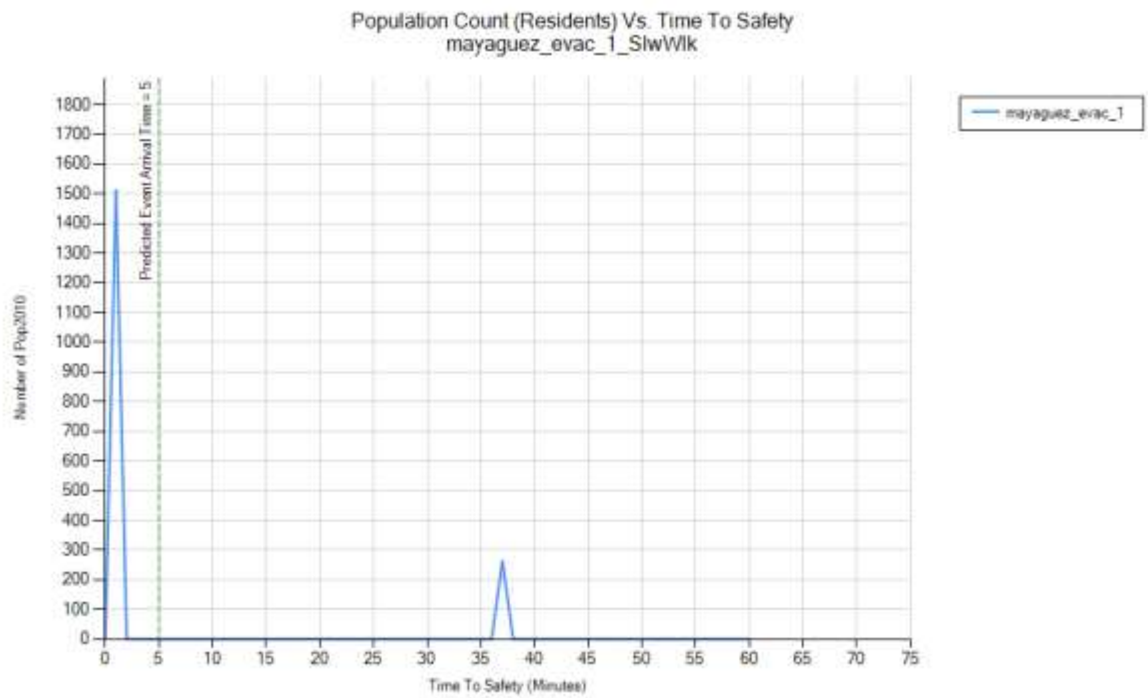



Figure 7 Time that takes the residents within the TEZ to evacuate to the safe zone

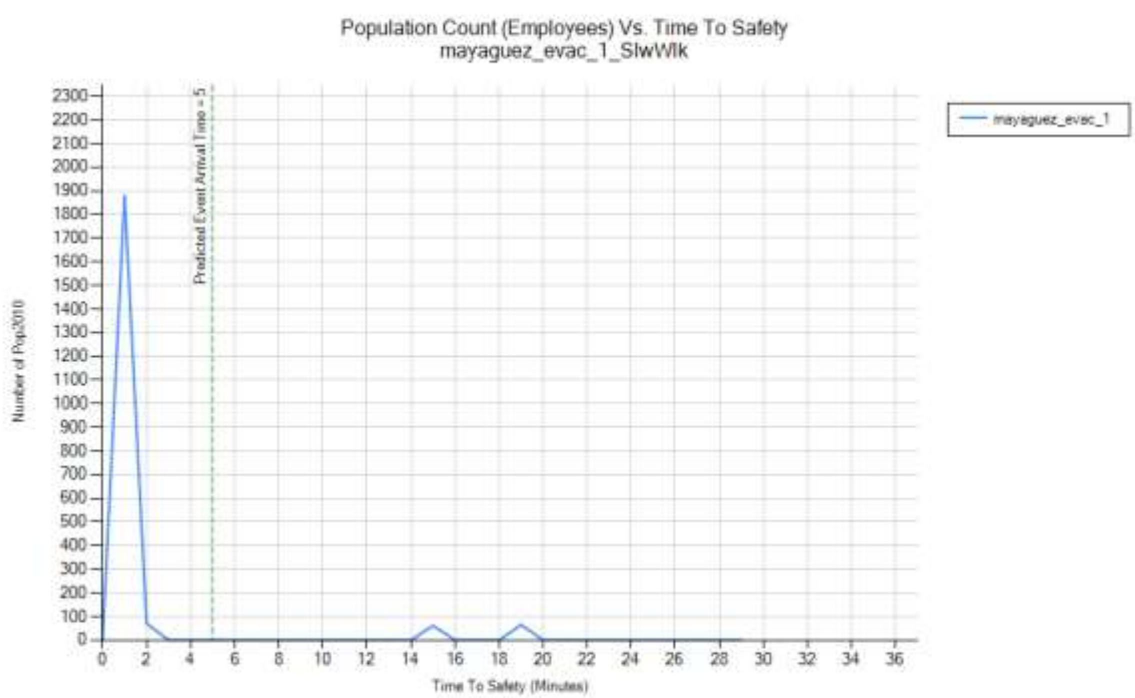



Figure 8 Time that takes the employees within the TEZ to evacuate to the safe zone

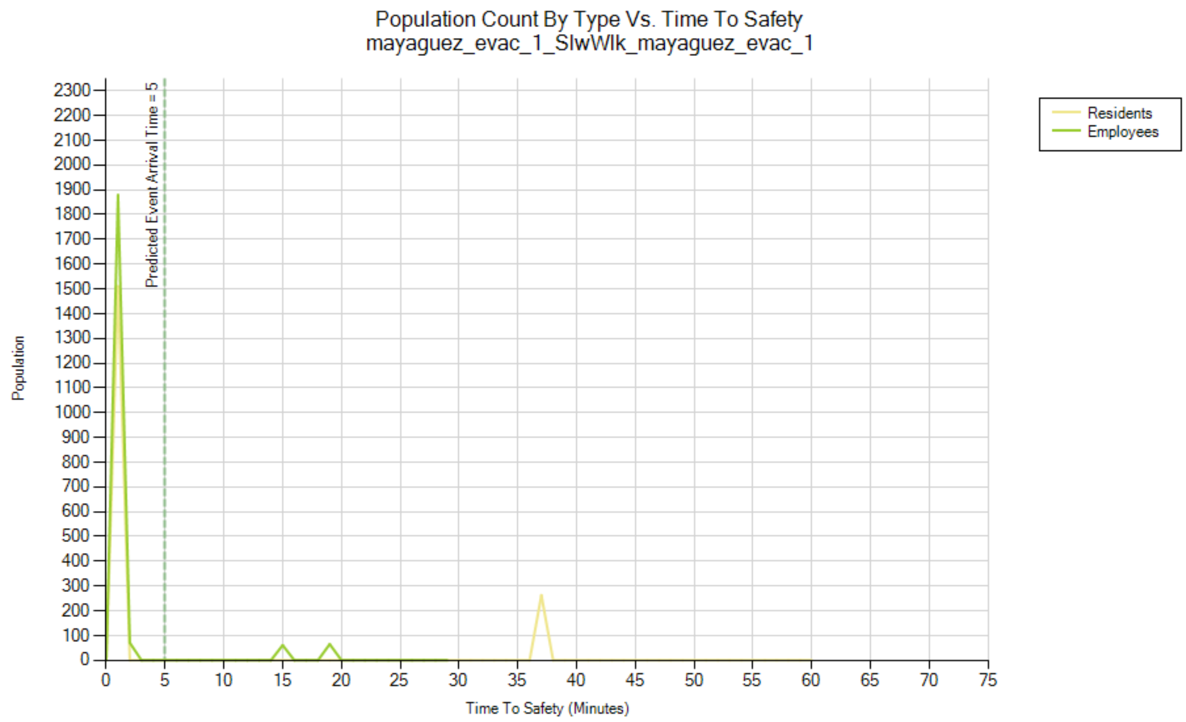



Figure 10 Time that takes, both the employees and the residents within the TEZ to evacuate to the safe zone

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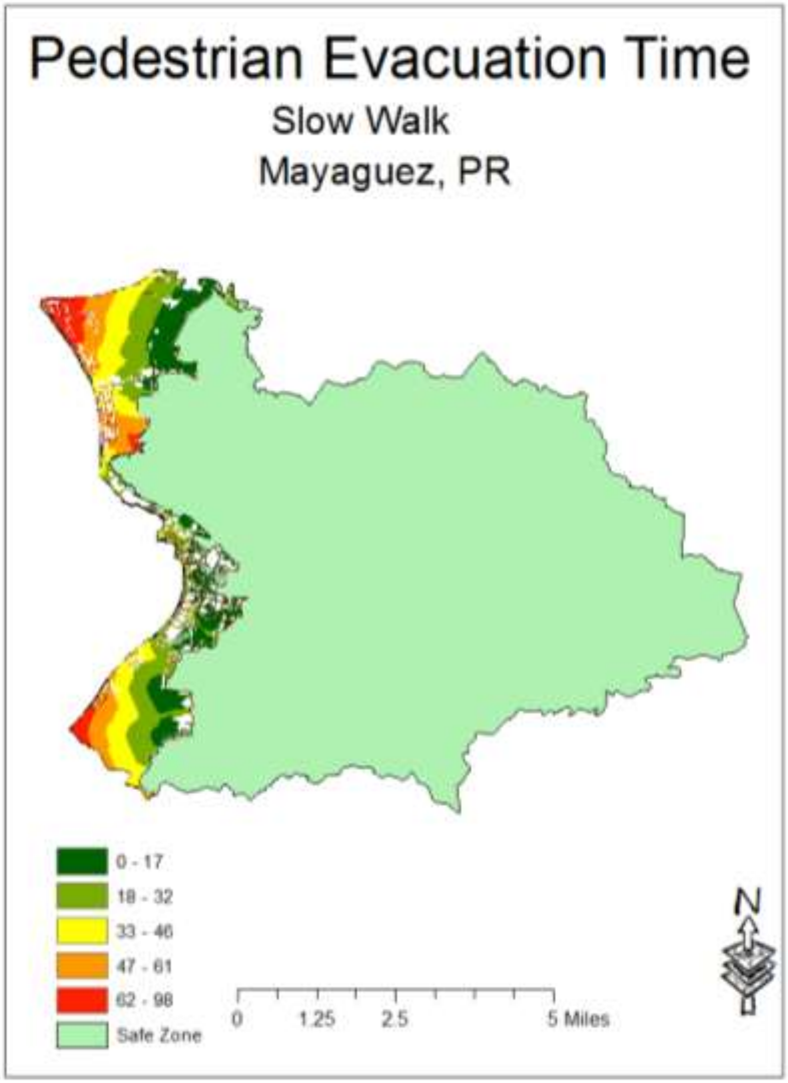


Figure 11 Pedestrian Evacuation Time Map for the Mayagüez Area showing time in minutes that would take for pedestrians to arrive to the safe zone.

## Tables

| Tool name | Input files | File type |
|---|---|---|
| DEM preprocess | DEM study-area outline (optional) | Raster Vector |
| Land-cover preprocess | Base land cover<br>Ancillary layers, such as roads, buildings, water (optional) | Raster or vector<br>Raster or vector |
| Hazard-zone preprocess | Hazard layer | Vector |
| Path distance | Edited and verified safe zone | Vector |
| Vertical evacuation | VE locations, polygon | Vector |
| Population | Multiple population type files, such as residents, employees, and de-pendent care (minimum of 1 file) | Vector |

Table 1 Required input files for various pedestrian Evacuation Analyst processing steps (Jones, et al., 2014).

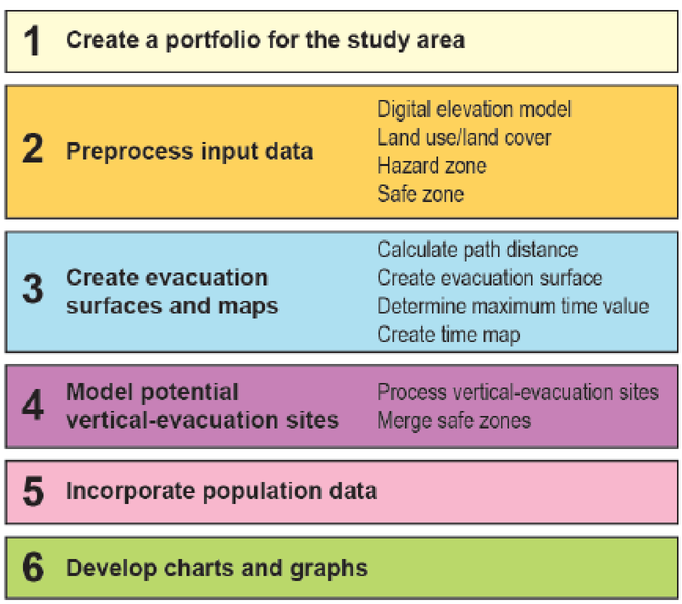


Table 2 Pedestrian Evacuation Analyst Workflow (Jones, et al., 2014)

| Travel-speed name | Travel-speed value[1] (meters/ second) |
|---|---|
| Slow walk | 1.1 |
| Fast walk | 1.52 |
| Slow run | 1.79 |
| Fast run | 3.85 |
| Other | 0 (user enters value) |

Table 3 Travel-speed names and corresponding values in the Pedestrian Evacuation Analyst (Jones, et al., 2014).

| | |
|---|---|
| CONSTRUCTION | 2159 |
| HIGH-DENSITY RESIDENTIAL | 18861 |
| HIGH-DENSITY TRADE AND SERVICES | 573 |
| INDUSTRIAL | 74 |
| INFRASTRUCTURE | 1370 |
| LOW-DENSITY RESIDENTIAL | 1774 |
| **Grand Total** | **24811** |

Table 4 Population density for Mayagüez (Census, 2010)

**References**


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WebMap for Pedestrian Evacuation of Mayaguez http://bit.ly/1vAYNjv

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