A More Comprehensive Vulnerability Assessment:

Flood Damage in Virginia Beach

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Introduction

One of the most obvious effects of flooding events is death. Humans may either get swept away quickly by a flood, or hit by large chunks of debris. Property damage may also occur as debris are blown into buildings by floods. In addition, floodwater contaminated with sewage may pollute sources of drinking water as it returns back to a river.[1] Most interesting, however, is the damage that is done to automobiles, and its resulting effects. This occurs regardless of whether a car is parked or driving on a road. Most municipalities have prepared, to some degree, for flooding's effect on automobiles and roads, by indicating certain thoroughfare streets as evacuation routes in the event of a disaster. Others might have gone a step further, by equipping certain roads with stormwater infrastructure or impervious cover methods to remove floodwater from the roads at a faster pace.

The topic of automobile damage was brought up by the recent events of Hurricane Harvey. Houston is a geographically large city in which much of the population relies on automobiles- either personal vehicles or carpooling- as a primary source of transportation, as the Houston METRORail and METRO buses do not cover enough of the city to be considered a reliable source of transportation for many citizens. The damage to vehicles done by Hurricane Harvey left several citizens without a dependable source of transportation. Many images in the media showed several roads completely flooded. It is quite possible that Houston did not possess an understanding of which areas within its jurisdiction were most vulnerable to flooding. Future disaster planning efforts may be aided by an understanding of which roads and intersections are at greater risk of flooding and flood damage.

Though recent storms have mostly affected the southeastern United States, the coast adjacent to the Atlantic Ocean is also quite vulnerable, as demonstrated by the events of Hurricane Sandy in 2012. While several large metropolitan areas are close enough to the coast to be in danger in the event of a hurricane or flood, few are as close to the edge as the City of Virginia Beach. The largest city in the state of Virginia, Virginia Beach is a huge contributor to the state in tax revenue derived from tourism, a large part of the local economy. While not as geographically large as Houston, Virginia Beach is also quite automobile dependent. The City does not use any form of rail transit, and only has a few bus routes that travel within its jurisdiction.[2] Only 1% of the population uses either these routes or paratransit. In addition, one-tenth of the population utilizes carpooling for commuting.[3] In order to ascertain whether a GIS analysis was necessary, an inspection of the Virginia Beach hazard resiliency and mitigation plan was needed.

Hampton Roads Hazard Mitigation Plan

[1] Jackson, Alex. "Factors Affecting Flood Frequency." Geography AS Notes, 2 Aug. 2014, geographyas.info/rivers/flooding/. Accessed 8 Dec. 2017.

[2] "Virginia Beach Routes." Hampton Roads Transit, gohrt.com/route/virginia-beach/. Accessed 8 Dec. 2017.

[3] "Virginia Beach, VA." Census Reporter, censusreporter.org/profiles/16000US5182000-virginia-beach-va/. Accessed 8 Dec. 2017.

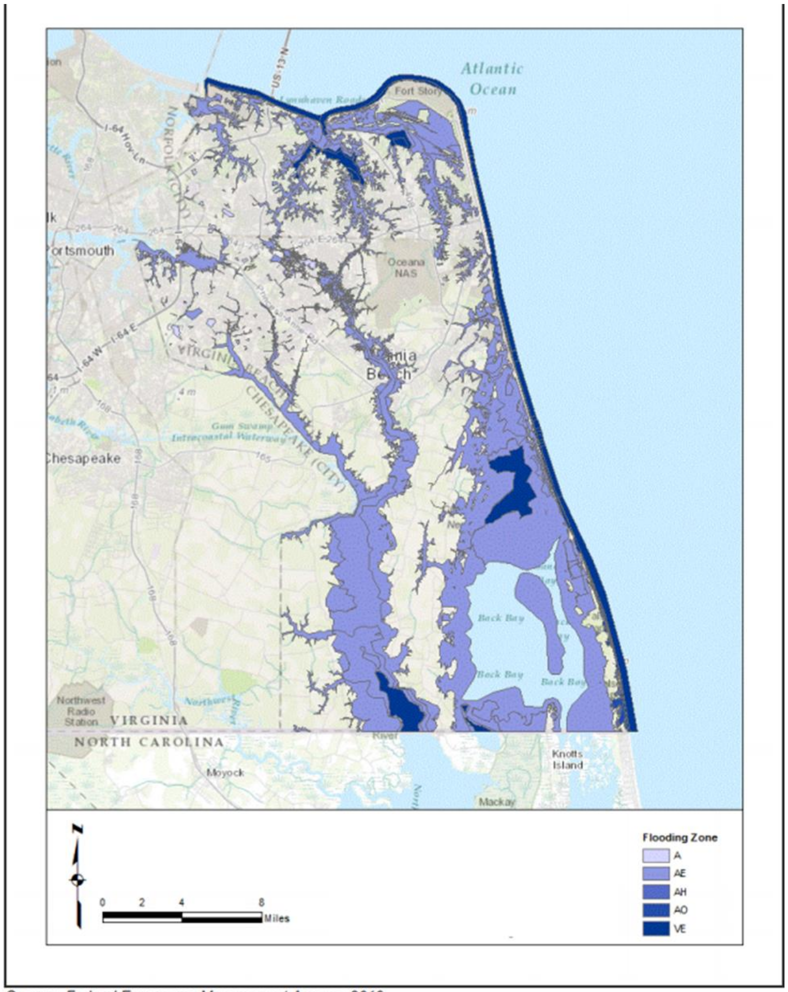
The City of Virginia Beach does not have its own disaster resiliency and mitigation plan. A Hazard Mitigation Plan has been published by the Hampton Roads Region of southeastern Virginia municipalities, including Hampton, Newport News, Poquoson, James City County, Williamsburg, York County, Norfolk, Portsmouth, Virginia Beach, Chesapeake, and Suffolk. While the plan provides general background information, location and spatial extent, and historical occurrences for multiple hazards in addition to flooding, there is no current information on evacuation routes.[4] However, the plan currently states that "Evacuation and sheltering plans for vulnerable populations are a high priority for the region's emergency planners at this time, and Western Tidewater planners continue to work with NC officials regarding Outer Banks evacuation routes that traverse the region."[5] Thus, it would be prudent to observe which streets and routes are most vulnerable to flood damage using a GIS analysis.

The spatial extent of the most vulnerable areas is indicated solely by the 100-year floodplain for the city of Virginia Beach, as indicated below in *Figure 1*.[6]

[4] "Hampton Roads Hazard Mitigation Plan: Mitigation Strategy." City of Virginia Beach, Jan. 2017, www.vbgov.com/government/departments/emergency-management/Documents/7-%20Mitigation%20Strategy.pdf. Accessed 8 Dec. 2017.

[5] "Hampton Roads Hazard Mitigation Plan: Hazard Identification and Analysis." City of Virginia Beach, Jan. 2017, www.vbgov.com/government/departments/emergency-management/Documents/4-%20Hazard%20Identification%20and%20Analysis.pdf. Accessed 8 Dec. 2017.

[6] "Hampton Roads Hazard Mitigation Plan: Mitigation Strategy." City of Virginia Beach, Jan. 2017, www.vbgov.com/government/departments/emergency-management/Documents/7-%20Mitigation%20Strategy.pdf. Accessed 8 Dec. 2017.



Source: Federal Emergency Management Agency, 2016

Figure 1, City of Virginia Beach 100-Year Floodplain

While one could theoretically observe which roads fall within the 100-year flood plain, this analysis fails to factor vertical heterogeneity- that is to say, certain streams may have higher base flood elevation levels. And while topographic elevation levels are closer to 0 in coastal cities, the entire city is not located at one constant elevation. Thus, a reverse suitability analysis was performed with additional variables to identify the spatial extent of Virginia Beach's areas most vulnerable to flood damage.

Methodology

Variables in addition to the 100-year flood plain included Annual Average Daily Traffic measures, stream base flood elevation levels, population density at the tract level, and elevation. Data for these variables was obtained from the Virginia Department of Transportation (VDOT), FEMA's Flood Map Service Center, the City of Virginia Beach, and the USGS. Below, *Figures 2-6* show visual representations of these variables.

Figure 2, City of Virginia Beach Jurisdiction

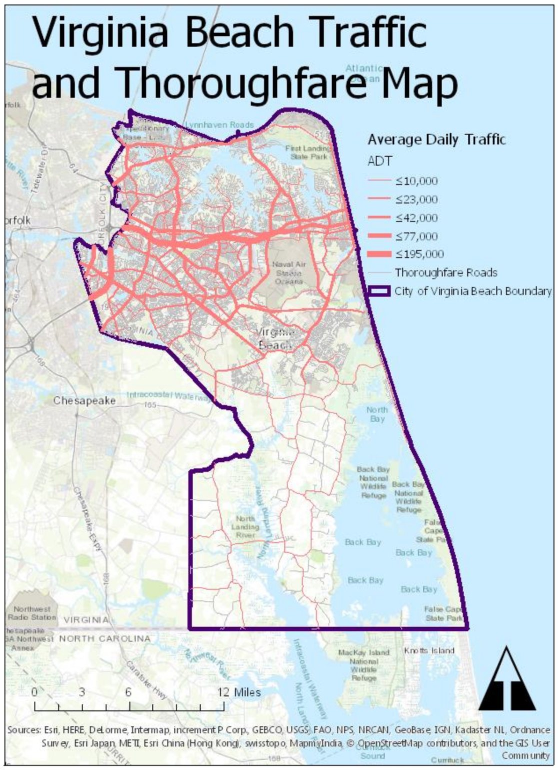


Figure 3, City of Virginia Beach AADT/Thoroughfare Map

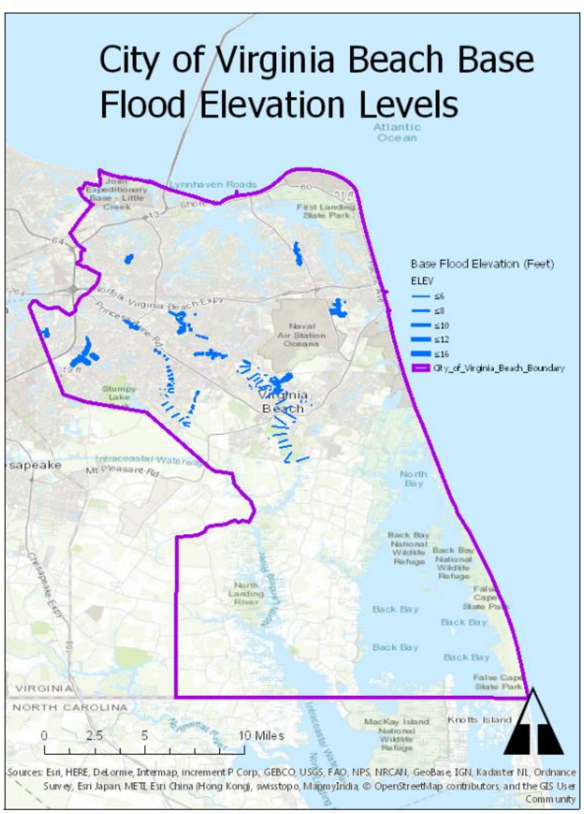


Figure 4, City of Virginia Beach Base Flood Elevation Levels

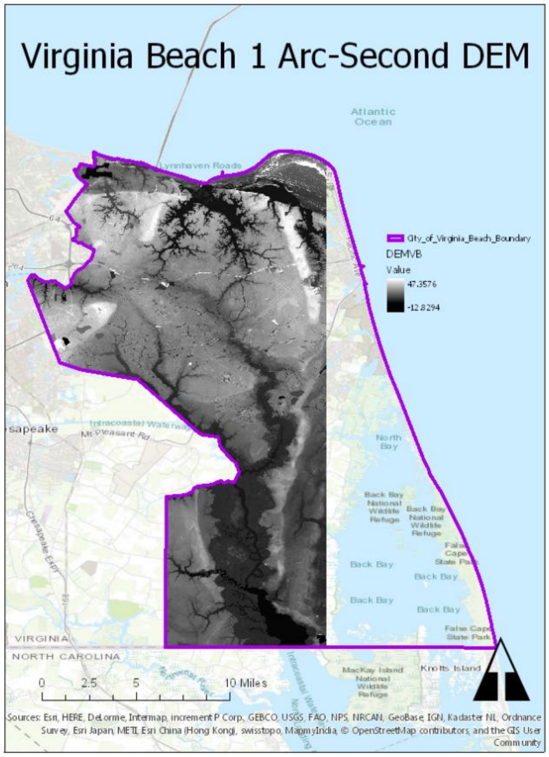


Figure 5, Virginia Beach Digital Elevation Model

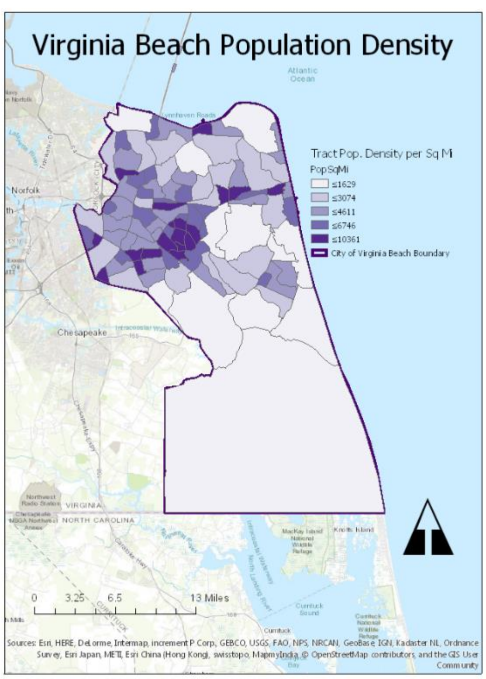


Figure 6, Virginia Beach Population Density

The DEM layer was then converted to show slope percentages, shown below in *Figure 7.*

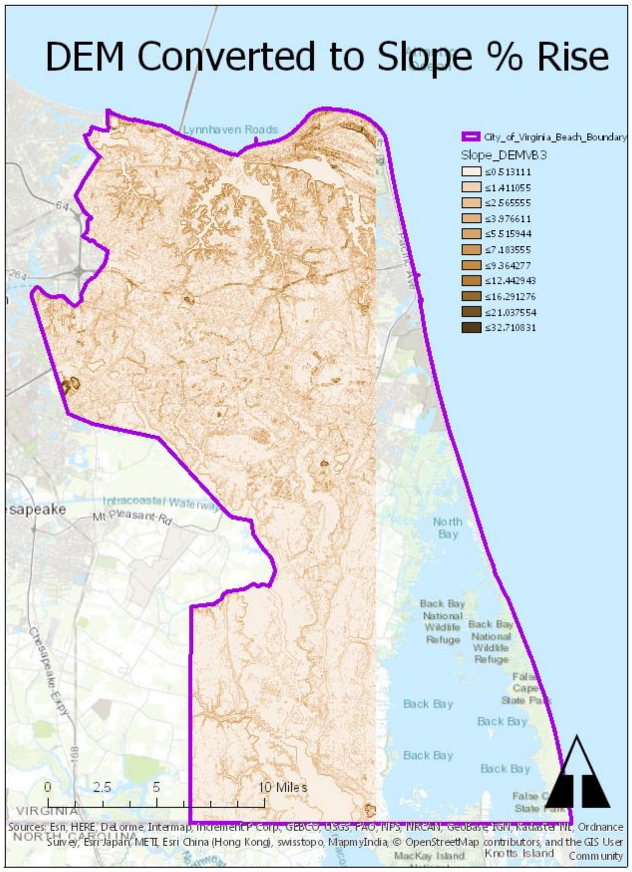


Figure 7, Virginia Beach Slope % Rise

The next step involved narrowing down data within each variable to examine. Inspecting the average annual daily traffic measures of New York State found that most municipalities had annual average daily traffic measures close to 10,000 vehicles per day.[7] Thus, only roads in Virginia Beach that had AADT measures of 10,000 or more were considered. The average of base flood elevation for all stream data in Virginia Beach totaled 8.13. Therefore, all streams with BFE levels of 8 or more were considered. When natural breaks were used to symbolize the population density, the lowest category amounted to less than or equal to 1,672 individuals per square mile. Thus, only tracts with population densities greater than 1,672 individuals per square mile were considered.

[7] "Annual Average Daily Traffic (AADT): Beginning 1977." Data.Gov, 16 June 2016, catalog.data.gov/dataset/annual-average-daily-traffic-aadt-beginning-1977. Accessed 8 Dec. 2017.

Once this was done, the Euclidean distance function was used to convert vector data to rasters and symbolize higher priority for values located further away from each of these variables. A maximum distance of 500 feet was used for each of the variables. *Figures 8-11* below show the result of the Euclidean distance function.

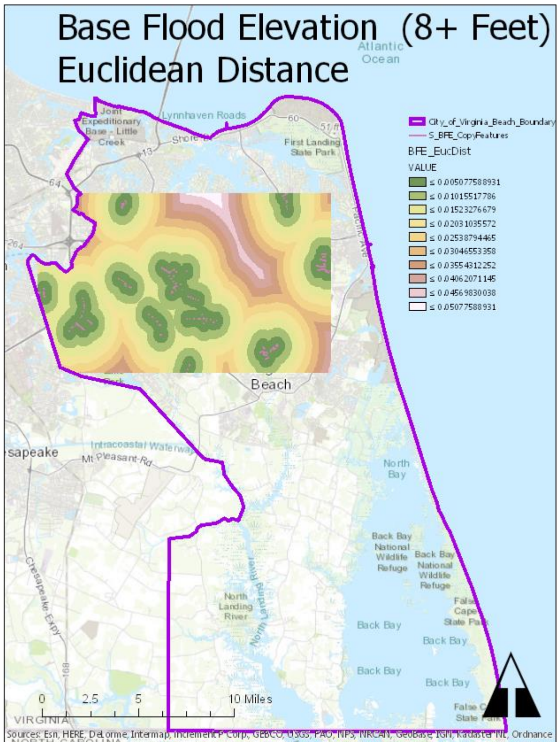


Figure 8, BFE Euclidean Distance Map

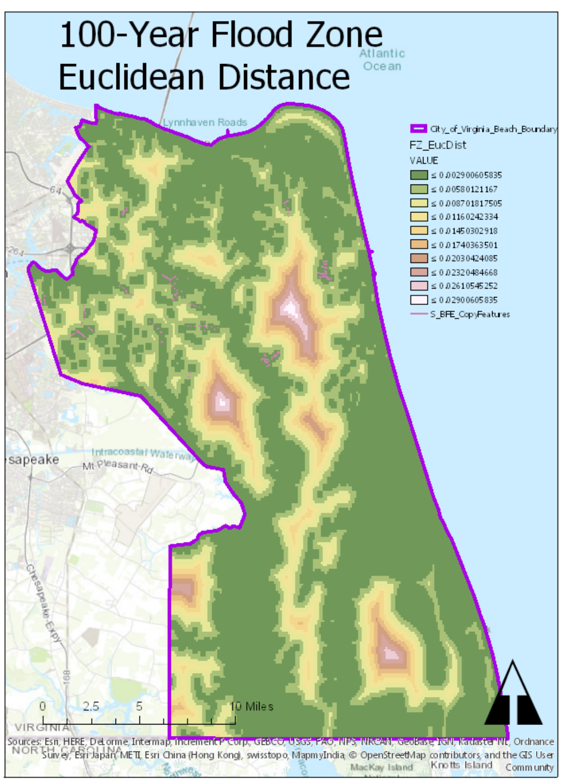


Figure 9, 100-Year Flood Zone Euclidean Distance

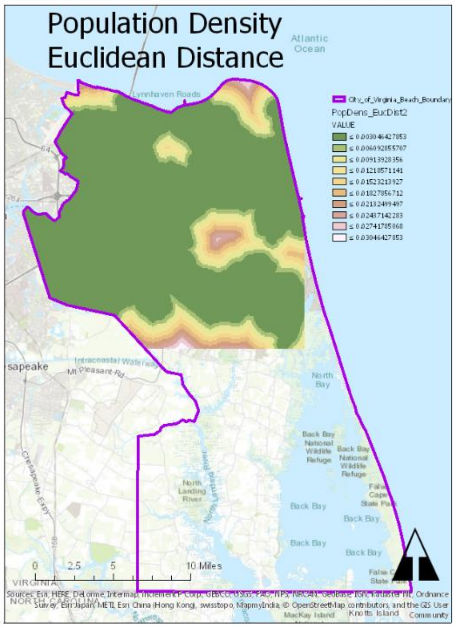


Figure 10, Population Density Euclidean Distance

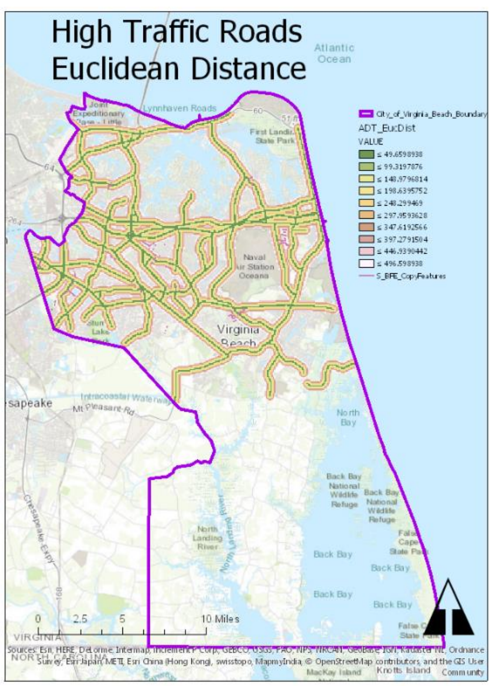


Figure 11, High Traffic Roads Euclidean Distance

The next step involved reclassifying all variables using the reclassify function. *Figures 12-16* below show the results.

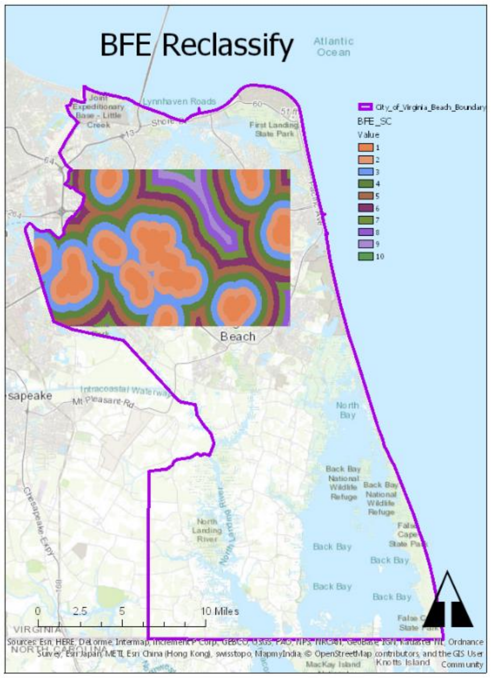


Figure 12, Base Flood Elevation Reclassification

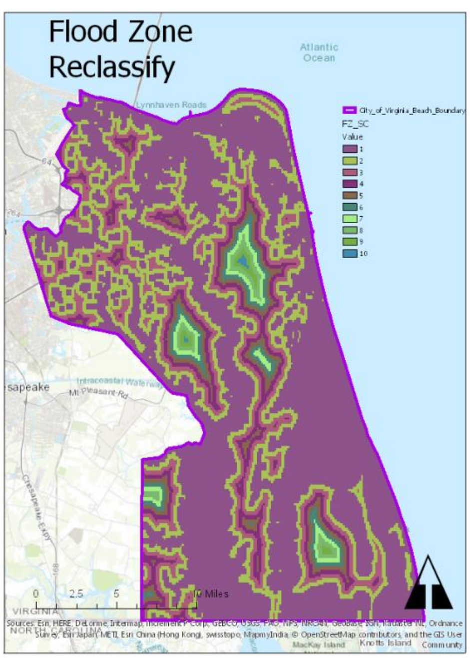


Figure 13, 100-Year Flood Zone Elevation

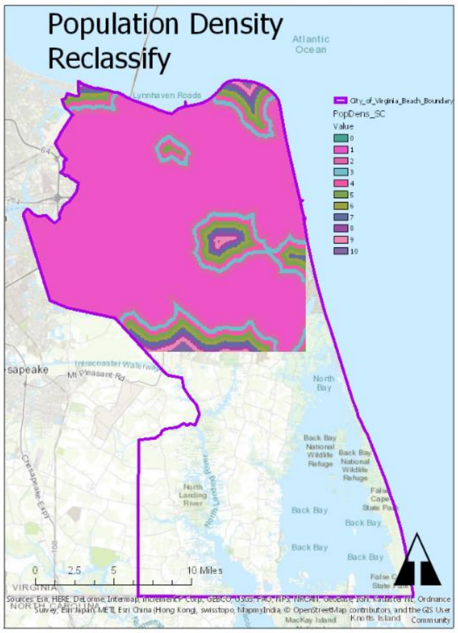


Figure 14, Population Density Reclassification

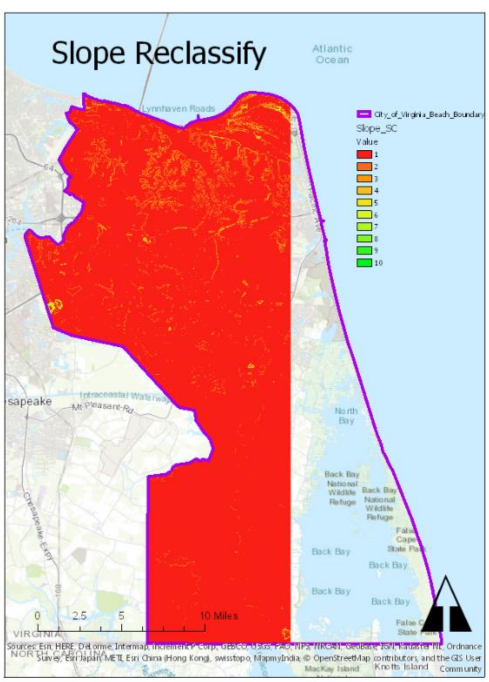


Figure 15, Slope Reclassification

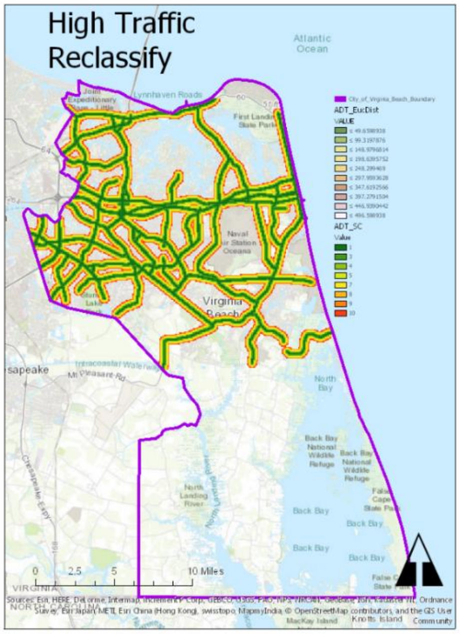


Figure 16, High Traffic Reclassification

Once all variables were reclassified, the raster calculator function was used to identify a spatial extent with all variables. Each variable was assigned a weight during this process. Common knowledge indicates that flood zones, elevation, and high base flood elevation levels would factor in heavily into a spatial assessment for flooding- thus, they were each given a weight of 25%. As previously discussed, roads with high traffic are more susceptible to flood damage than others. Thus, the annual average daily traffic measures variable was given a weight of 15%. Population density at the tract level was given the remaining weight of 10%. *Figure 18* below shows the resulting calculation.

Figure 18, Raster Calculation from Weighted Variables

This raster calculation was then reclassified with 5 values instead of 10, and converted to a polygon using the raster to polygon function. Once a polygon was created, the select by attributes function was used to select the areas where the field "Gridcode" equaled 1 or 2. In other words, it selected the areas closest to the aggregated threat- the most vulnerable to flood damage. The final result can be viewed below in *Figure 19*.

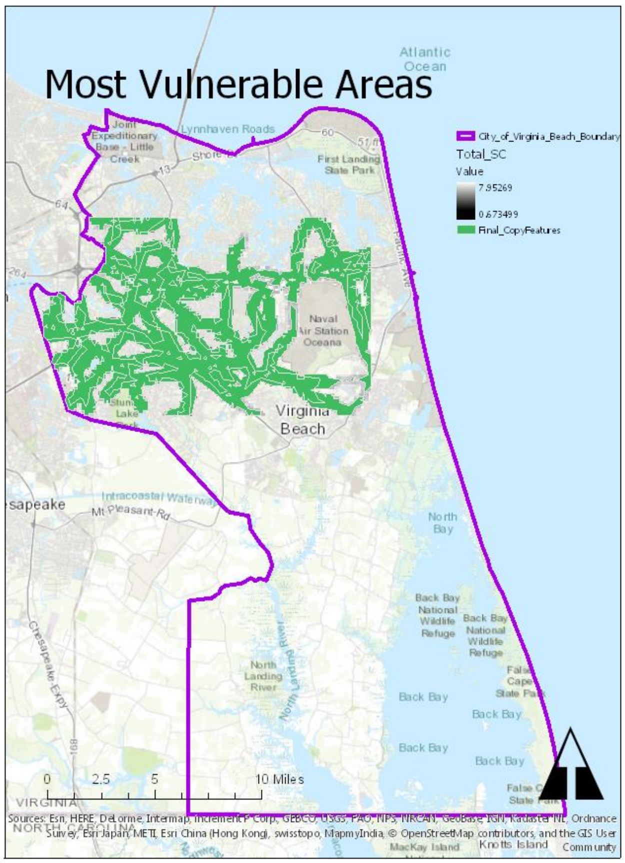


Figure 19, Virginia Beach Most Vulnerable Areas

Conclusion

As *Figure 19* indicates, the most vulnerable areas don't appear to overlap with a majority of the floodplain, and are concentrated on the areas with major highways, municipal arterial streets, and waterways with high base flood elevations. Major roads that fall within this spatial extent include Interstate Highway 64, Interstate Highway 264, Virginia State Route 165, Virginia State Route 225, General Booth Boulevard, Indian River Road, Independence Boulevard, and

Virginia Beach Road. The identification of these routes is significant for informing the process of determining evacuation routes, and could potentially be shown to planners and resiliency professionals that are currently working on identifying routes in the Outer Banks region.

However, there were a few issues involved with performing this analysis. The DEM data downloaded, both 1 and 1/3 arc second DEMs, did not have any coverage of the coastline. While the coastline elevation is assumed to be 0 or close to 0, this may have affected the analysis. Problems with the Euclidean distance function included an inability to set a uniform cell size, which may have led to the omission of certain areas of the city in the analysis.

Despite the issues involved with performing this analysis, the inclusion of other factors when assessing the spatial extent of flood risk is quite important. Hopefully in the future, as municipalities continue to assess their most vulnerable areas, they will incorporate a holistic understanding of how far-reaching a natural disaster's effects truly are.