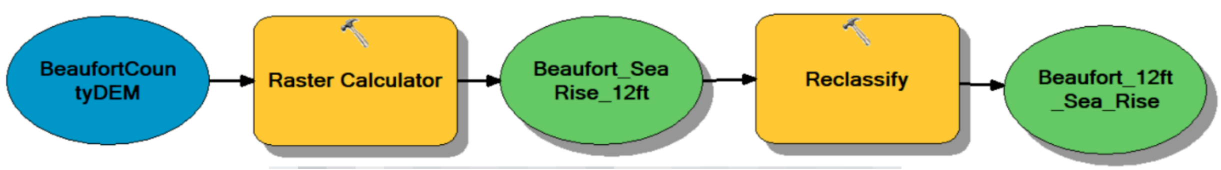
Introduction.

Climate change and coastal sea rise directly affect the marsh barrier islands in Beaufort County, South Carolina, located in an area aptly nicknamed the "low country." Hurricanes often batter the eastern coast of North America, and these low-lying marsh areas are susceptible to floods and storm surges. On August 27, 1893, the Great Sea Island Hurricane made landfall at Beaufort County, South Carolina's barrier islands, with a 10 to 12-foot storm surge at high tide. A large portion of the population in Beaufort County at the time was African American, freed slaves, and their families that lived in communities on the barrier islands, Like St. Helena Island. Because these communities were isolated from the mainland, they received little to no communication that a storm was coming. The African American communities had made a modest living, building wood houses and living off the land, but they were unprepared for an extreme disaster. Estimates have reported at least 2,000 casualties, but the numbers are likely higher due to the inability to communicate or report deaths from isolated areas. “The devastating human cost began to become apparent in an Aug. 31 story that reported at least 600 dead in the Beaufort area…Almost all of the dead came from black families who had begun to farm the sea islands after the Civil War… By the Sept. 2 newspapers, the death toll was about 1,500. More than 300 were on St. Helena Island alone.” (Holleman, 1999). The Sea Islands Hurricane was, at the time, considered the third largest natural disaster and was the first hurricane significant hurricane relief effort from the American Red Cross. Given that technology today has rapidly advanced how we communicate, track, and prepare for extreme weather events, a model was created in ArcGIS Desktop software to replicate the 12-foot storm surge and analyze how that would affect the coastal population today. Has the coastal population become more resilient in the last 120 years, or has time erased the fears of another disaster?

Methods.

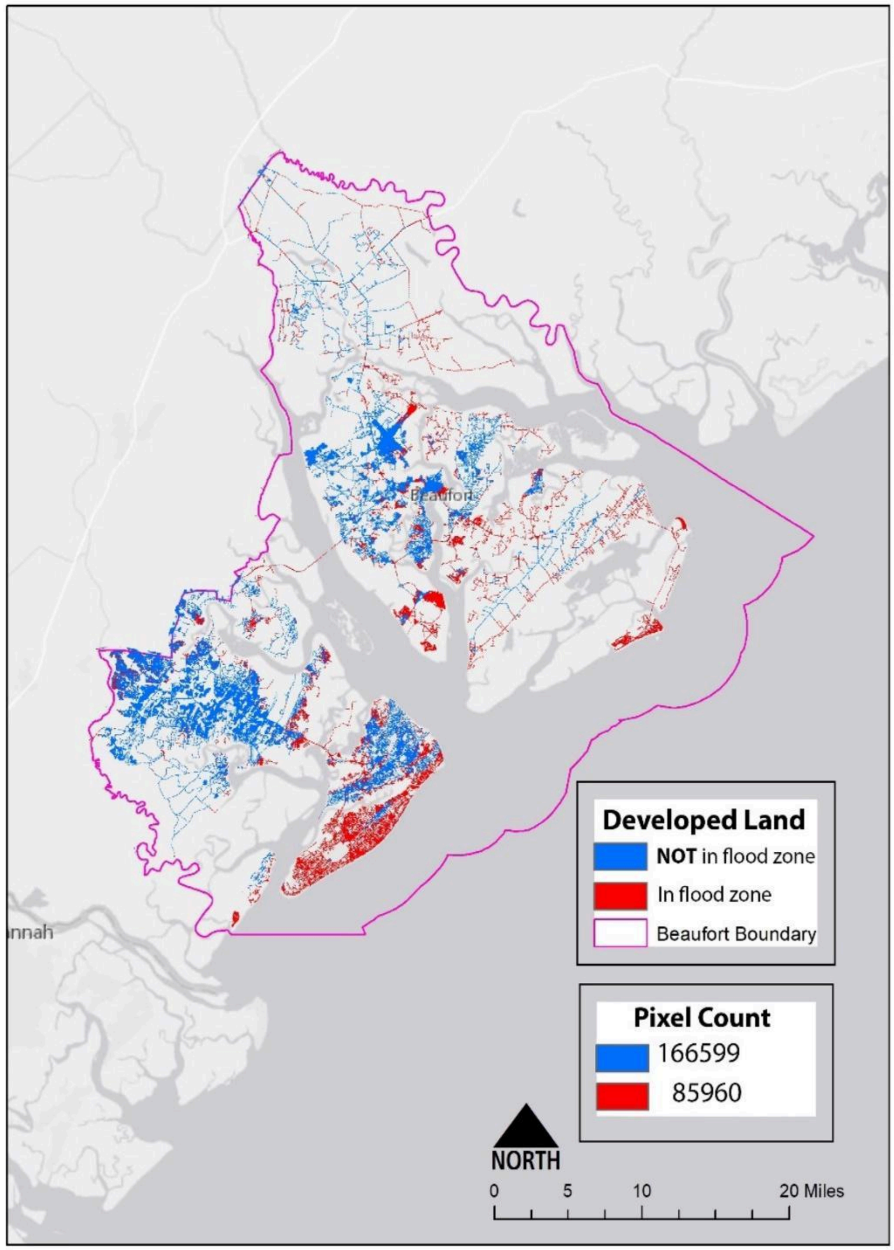
1. **Determining Risk to Exposure**
    a. **Bathtub Model**



The first step of this analysis was to create a bathtub model to determine coastal flooding. “The bathtub inundation model assumes that an area with an elevation less than a projected flood level will be flooded like a “bathtub”. Flooding areas are determined through a simple calculation procedure in a GIS environment where the elevation in each cell of a DEM is compared against a predicted sea level and all cells with values lower than the predicted sea level are considered flooded.” (Yunus et al., 2016). The South Carolina DNR LiDAR DEM with a 5 Foot resolution downloaded from NOAA.gov. The DEM was mosaicked into four tiles, added to a geodatabase, and combined as a mosaic dataset to make a seamless elevation model. The bathtub model was created in ArcGIS Model Builder (*figure 1*). The Raster Calculator tool was used to perform the calculation **"%BeaufortCountyDEM%" <= 12** , where 12 denotes the 12 foot rise in sea level. The Reclassify tool was then used on the output to convert the raster into a binary format, where 1 equals area within the flood zone, and 0 equals NoData.

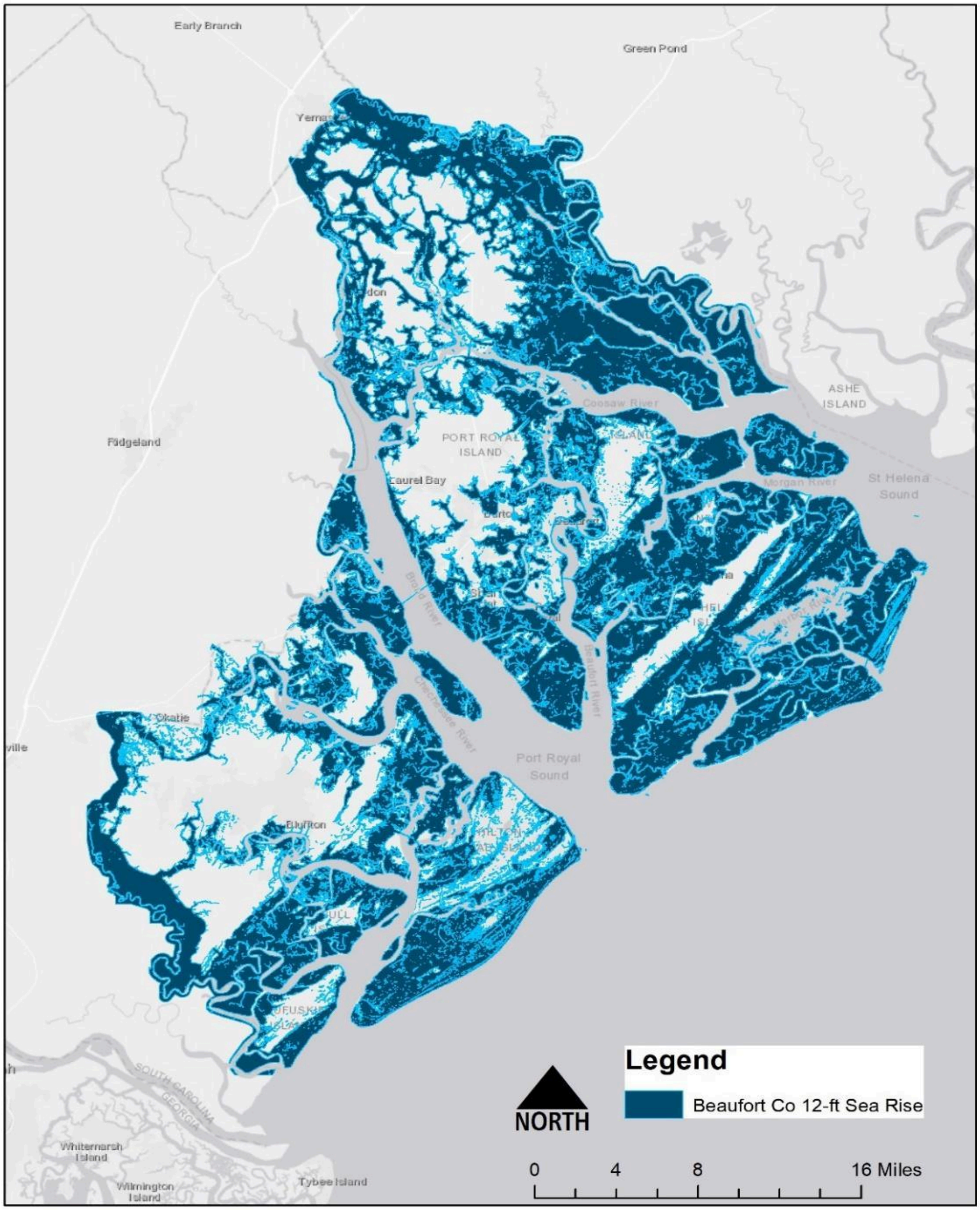
b. Using NLCD to determine urban land in flood zones

The National Land Cover Database (NLCD) 30-meter resolution raster dataset was downloaded from Multi-Resolution Land Characteristics (MRLC) Consortium. “The Multi-Resolution Land Characteristics (MRLC) consortium is a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications” (MRLC.gov). Using the Reclassify tool in ArcMap, The NLCD dataset was reclassified to a binary raster, where 1 equals all developed land (Developed, Open Space/Developed, Low Intensity/Developed, Medium Intensity/Developed, High Intensity) and 0 equals all other land cover classes. The environment settings were adjusted to only process the raster image for the area within Beaufort County.



The reclassified NLCD binary raster was overlaid over the bathtub model output using the raster calculator to create two new raster datasets, the developed land in and not in the 12-foot storm surge. The conditional statement to calculate the developed land in flood zone is **Con(("Beaufort_SeaRise_12ft_fz" == 1) & ("Developed_Land" == 1),1,0)** and developed land NOT in flood zone is **Con(("Beaufort_SeaRise_12ft_fz" == 0) & ("Developed_Land" == 1),1,0)**.

Figure 2: Bathtub model showing the level of inundation a 12-foot sea rise would cause in Beaufort County,SC.



The final step of this process was to use the Zonal Statistics as a Table tool to create tables of the developed land in flood zones and developed land not in flood zones, then to join the ObjectID of the census tract polygon data (discussed in detail below) to determine urban exposure to flood (*figure 3*).

2. Determining Population Exposure to Hazard

To determine population information, American Community Survey 1-year (2018) data were downloaded from Census.gov as a Census Tracts Geodatabase with Selected Demographic and Economic Data. TIGER/Line county boundary files were also downloaded and utilized as the boundary for previous raster analyses. The geodatabase contained selected demographic tables in the appropriate order and required no editing. The Poverty, Race, and Age tables were joined on the GEOID of the census tract polygon for the following analysis. Calculations to determine population was done in the ArcGIS attribute table using the field calculator. These calculations are based on the assumption that populations and races are distributed equally across the census tracts.

Race

B02001e1	RACE: Total: Total Population -- (Estimate)
B02001e2	RACE: Total: White alone: Total Population -- (Estimate)
B02001e3	RACE: Total: Black or African American alone: Total Population -- (Estimate)
B02001e4	RACE: Total: American Indian and Alaska Native alone: Total Population -- (Estimate)
B02001e5	RACE: Total: Asian alone: Total Population -- (Estimate)
B02001e6	RACE: Total: Native Hawaiian and Other Pacific Islander alone: Total Population -- (Estimate)
B02001e7	RACE: Total: Some other race alone: Total Population -- (Estimate)

The first step in determining the population in the flood zone was to use the calculation

$$\text{Population in Flood Zone} = \text{population} * \frac{\text{developed land in Flood Zone}}{(\text{developed land in FZ} + \text{developed land not in FZ})}$$

with the information from the total population data field (*figure 4*). The calculation was then repeated for each race category from above to determine the total population of each race in a flood zone (*Figure 5*). The totals were then rescaled using the calculation (x-min)/max-min for the next step, the social vulnerability analysis.

FZ_TOTAL_POP	r_TOTALPop_in_FZ	r_WhiteFZ	r_AA	r_NA_FZ	r_ASIAN_FZ	r_HAWAII_F	r_OTHER_FZ
130.225898	0.018744	0.01676	0.0056	0	0.042193	0.025	0.002401
263.849558	0.046199	0.054137	0	0	0	0	0
740.553693	0.144145	0.175443	0	0	0	0	0
975.251337	0.192367	0.220153	0.003979	0.117882	0.121677	0	0.010804
3968.836115	0.807445	0.807029	0.087902	0.384362	0.996927	1	0.051621
1103.509705	0.21872	0.257738	0	0	0	0	0.016807
1785.51059	0.358847	0.293596	0.128478	0	0.541495	0	0.09904
684.734321	0.132676	0.122678	0.046902	0	0	0	0.011405
1711.294725	0.343599	0.241902	0.219085	0	0.697574	0	0
1811.891516	0.364268	0.427759	0.003672	0.135627	0.31304	0.15	0
1140.07218	0.226232	0.266793	0.002257	0	0.066941	0	0.015606
1671.84578	0.335493	0.389109	0.002842	0	0.961817	0	0
1080.638173	0.214021	0.164069	0.074557	0	0.144572	0	0.067827
1758.065414	0.353208	0.332927	0.087747	0	0.17514	0	0.054622
1974.357869	0.397649	0.33616	0.107842	0	0.034246	0	0.088235
200.892119	0.033263	0.038267	0.004341	0	0	0	0.003001
96.10744	0.011734	0.0148	0.001765	0	0.041819	0	0
1598.941434	0.320514	0.128187	0.360005	0	0	0	0
1184.508929	0.235362	0.243803	0.013143	0	0.116345	0	0.064826
3652.083024	0.742363	0.843695	0.060669	0	0	0	0.012005
961.173168	0.189475	0.224358	0.00185	0	0.146693	0.25	0.001801
1536.772008	0.30774	0.135947	0.292074	0.998717	0.053452	0	0.004802
2483.303056	0.50222	0.341829	0.345887	0.09894	0.714879	0	0.003001
38.723464	-0.000057	-0.000013	0.002585	0.00441	0.004721	0	0.0012
3933.473358	0.800179	0.228646	0.999858	0	0.150934	0	0.034214
4095.800745	0.833532	0.999923	0.003544	0	0.420404	0	0

3. Social Vulnerability

Social vulnerability can be described as the incapability of a population or community to endure negative and unexpected stressors, in this case, in the form of an extreme weather event. “Social vulnerability is partially the product of social inequalities—those social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond. However, it also includes place inequalities—those characteristics of communities and the built environment, such as the level of urbanization, growth rates, and economic vitality, that contribute to the social vulnerability of places.” (Cutter et al., 2003). In this study, the Census data tables Age and Poverty were used to assess on the ratio of the total population in poverty (r_pov) and the total population over the age of 75 (r_75_up).

Poverty:
The total male and female living in poverty in the last 12 months (figure 6) were added together to equal total population in poverty. The ratio was determined by dividing the total population by the total population living in poverty.

B17001e2	Total Population in Poverty, Male	
B17001e17	Total Population in Poverty, Female	
	Total Population in Poverty	Total Population/Total in Poverty = r_pov

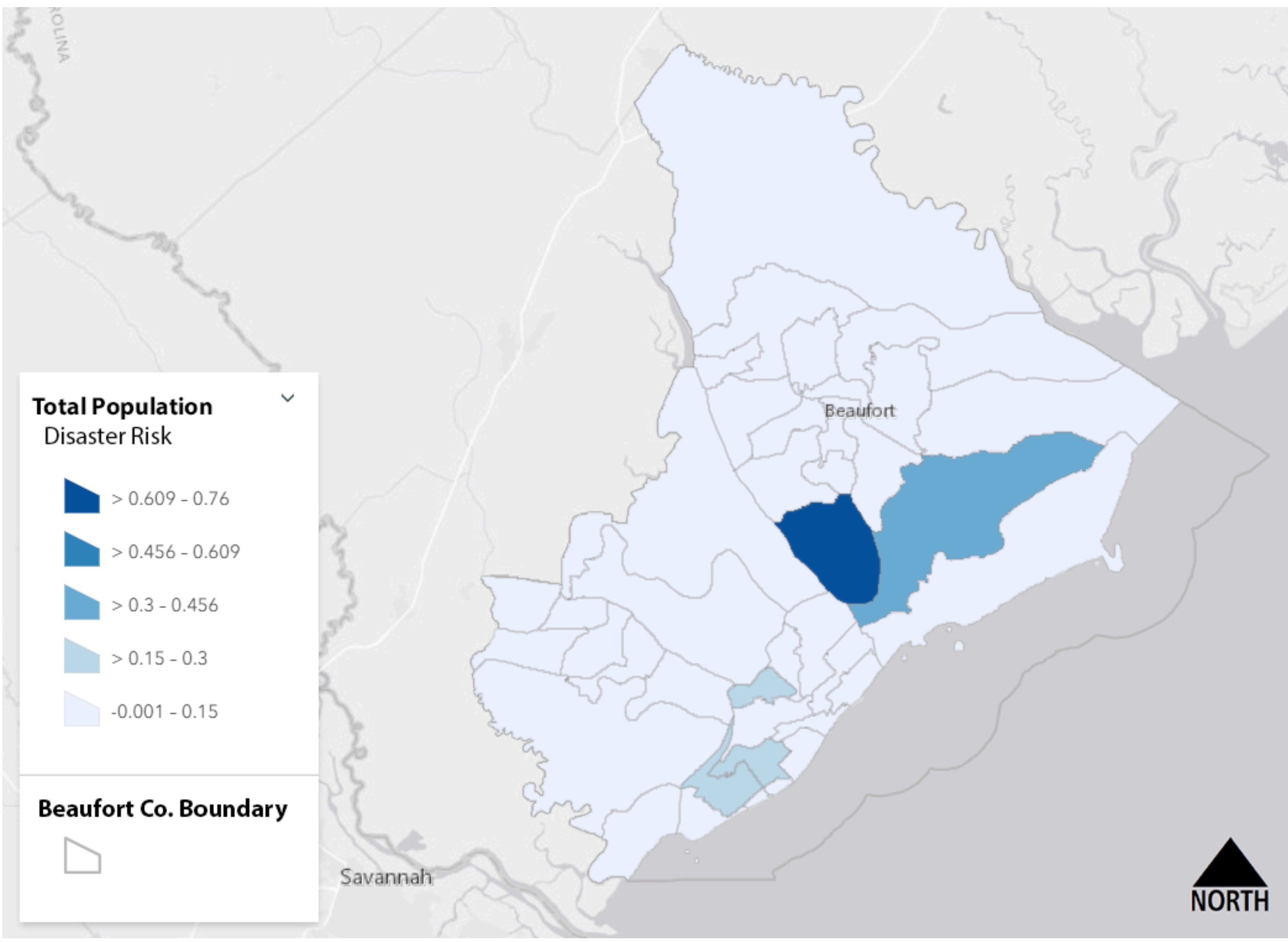
Age:
To get the total number of the population over the age of 75, a total of 6 data fields (*figure 7*) were added together. The ratio was determined by dividing the total population by the total over 75.

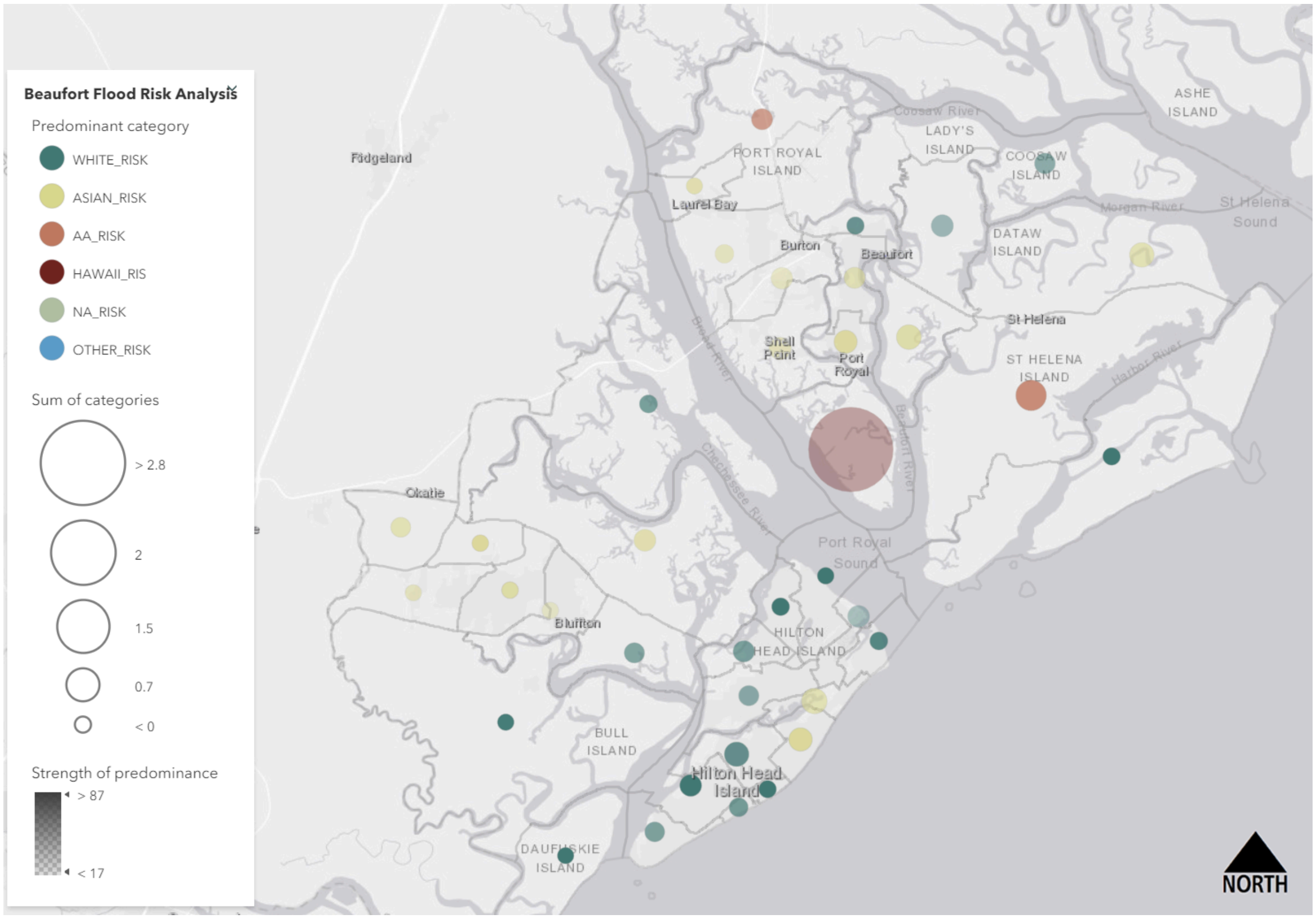
B01001e23	Total Population, Male 75 -79	
B01001e24	Total Population, Male 80-84	
B01001e25	Total Population, Male 85 and over	
B01001e47	Total Population, Female 75 -79	
B01001e48	Total Population, Female 80-84	
B01001e49	Total Population, Female 85 and over	
	Total Population Over 75	Total Population/Population over 75 = r_75_up

With the ratios of poverty and population over 75 determined, I used the calculation **Vulnerability Index = (5 * ratio of poverty) + (4* ratio of population over 75)**, where arbitrary weights to assign the ratio of poverty are higher than the weight of the ratio of population over 75. The vulnerability index was rescaled using (x-min)/max-min.

4. **Disaster Risk**

The final calculation done in the field calculator was the disaster risk, which can be determined by using the calculation **disaster risk = hazard * exposure * vulnerability**. In this study *hazard* has already been identified by the total population living in flood zones, *exposure* is the total population exposed to flood zones, and *vulnerability* is the vulnerability index from the previous step. The first calculation **Total Population in Flood Zones * Vulnerability Index** shows the disaster risk for the entire population of Beaufort County (*figure 8).* The disaster risk calculation was then used for the total population of each race in flood zones, for example **Total Population of African American in Flood Zones * Vulnerability Index**, to find the disaster risk for each race group.





Results

The results of this analysis were both fascinating and surprising. The first interesting outcome of the analysis was the large population of “Hawaiian or Other Native Pacific Islander” population located on Parris Island. Census.gov defines this race as “A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands. It includes people who reported their race as "Fijian," "Guamanian or Chamorro," "Marshallese," "Native Hawaiian," "Samoan," "Tongan," and "Other Pacific Islander.” (Census Quickfacts). This census tract is the Parris Island Marine Corps Recruit Military Training Depot. While this would need further analysis, I believe this value is high because of a large, isolated group living below the poverty level. The highest arbitrary weight value was given to the ratio of poverty.

Another stimulating result was the large Asian population at risk. The Census describes Asian as “A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam. This includes people who reported detailed Asian responses such as: "Asian Indian," "Chinese," "Filipino," "Korean," "Japanese," "Vietnamese," and "Other Asian" (Census Quickfacts). The high values of the Asian population at risk were unexpected, and further social vulnerability weights should be added.

The last thought-provoking outcome was looking at St. Helena Island (*Figure 9, northeast)*, where most of the African American casualties were located during the Sea Islands Hurricane in 1893. The African American population is still the most vulnerable population, with a risk score of .421 (out of 1).

The least surprising result of the analysis was that the southern portion of Beaufort County was least at risk and that most of the population at risk was defined as race being white. This area is Hilton Head Island, a popular area for vacations with high-priced condos and a lower level of poverty.

Conclusion.

While further analysis should be done to add other social vulnerability factors with less arbitrary weights to calculate of populations at risk, comparing the census data to the estimated damage after the 1893 Sea Islands Hurricane, I feel that it is safe to say the current population is more resilient than Beaufort County in 1893. Much of the resiliency comes from technological advances and better emergency management communications and preparation, but it is obvious by the bathtub model that a 12-foot sea rise would still be catastrophic for many populations affected by social factors that make them vulnerable.

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