Preparing for Sea Level Rise in Manhattan:

Spatial Analysis of Lost Land

and Displaced People

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Since 1880, global surface temperatures have increased by approximately 0.85°C and has caused a noticeable decrease in snow and ice cover. In turn, global sea levels have risen by 1.3 - 1.7 cm per decade, which has accelerated since the 1990s to around 3.2 cm per decade (Meehl, 2007). Specifically, New York's coast has seen sea levels rise around 3 cm since the 1990s on average. New York has also fallen victim to intense coastal storms that are expected to increase in number and magnitude (Horton et al., 2015). For example, Hurricane Sandy was the tropical storm that occurred in October 2012 that managed to cause 44 deaths in New York City with a 4.3m surge of floodwaters (Horton et al., 2015). This storm was not even half of what planners should be preparing for, as a 10m storm surge is expected to occur around once every 75 years (ESRI spatial Lab).

Risk management concerning climatic changes is necessary for planners to ensure the safety of citizens, which is made easier with GIS spatial analysis tools. Sea levels have already risen, nearing towards a new threat for the island of Manhattan, the most densely populated county in the state. This project seeks to answer three questions: How much land area and people would be inundated by a 10m storm surge for the year 2000? By climate model's predicted best-case scenario of a 0.28m or the worst-case scenario of 1.12m sea level rise for the year 2100? By a 10m storm surge in conjunction with the worst-case scenario? The study area in relation to New York state's other counties is shown in Map 1, which also displays land area and population ratios. This project seeks to identify Manhattan's at-risk land area and populations to visually represent how climatic changes will impact the region. The steps taken for this answered the questions of interest, which will not only benefit Manhattan, but any densely populated coastal state in preparation of lost coastal land.

Methods

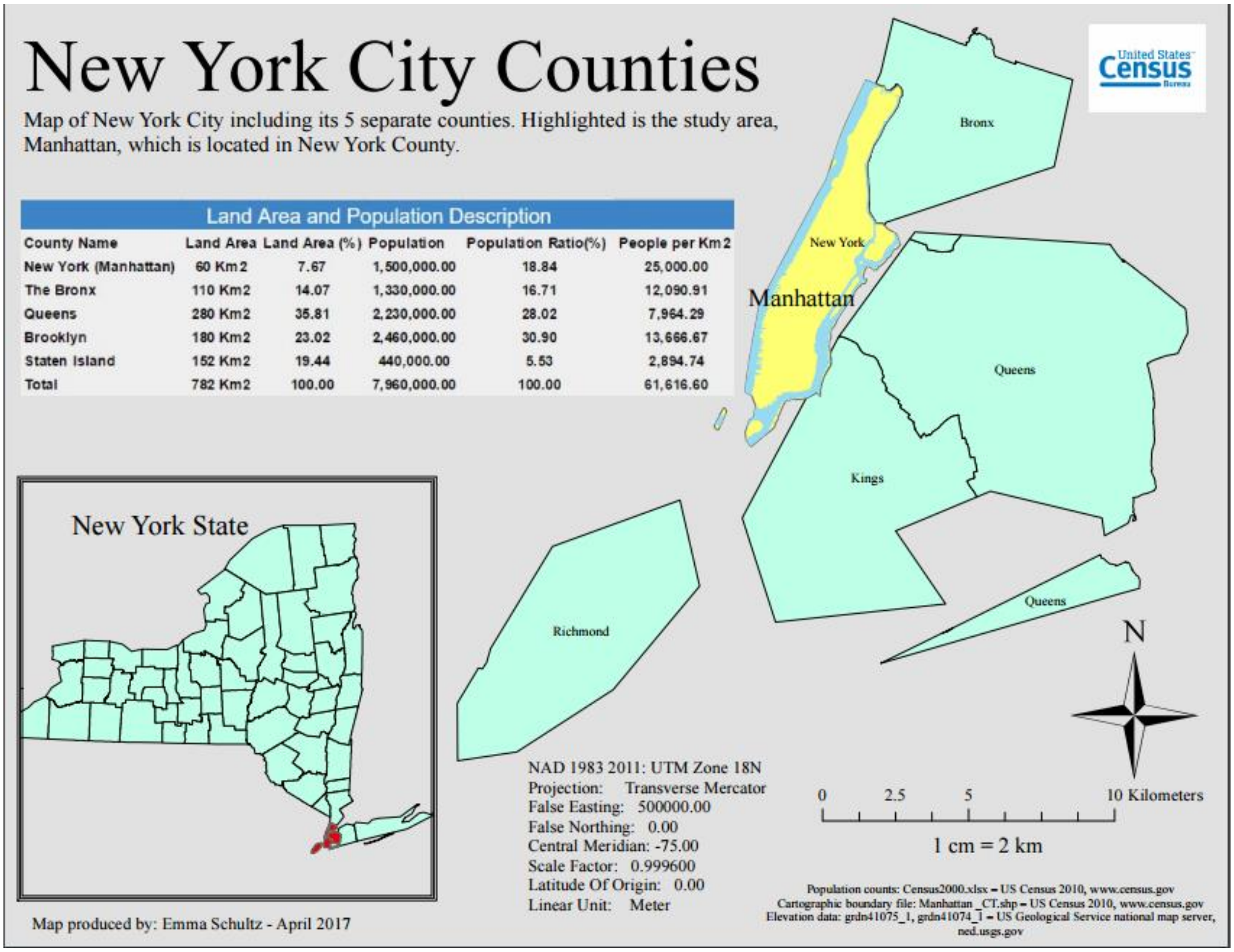
Estimations for the population in 2100 are based off the year 2000, with the assumption that growth will occur at the same rate as it has since 1940 and each census tract will grow at the same rate. The polynomial model is shown in figure 1 found in Appendix A, which was obtained from ESRI's spatial lab (Calef). With a population of approximately 1.5 million people in 2000, with a growth rate of 256%, the population will be approximately 3.9 million people by 2100. A field calculation was performed in the census tract shapefile's attribute table in a new field to obtain the population estimation, where density calculations per m2 per census tract was done to match the raster cell size of 30mX30m with the calculate geometry tool.

To identify the areas affected by the various sea level rise and storm scenarios, the conditional tool *Con* was utilized. Along with the digital elevation model of Manhattan as the input conditional raster each scenario's output raster was assigned a different odd-number as their "true" condition. For example, for the worst-cast scenario of 1.12m, the conditional expression reads: ["Value" >0 and "Value" <=1.12], and is given the number 3. Therefore, every cell within this range is labelled 3 in the attribute table, indicating land area under water, where all cells labelled 0 indicates land above water. A final grid was made using the *Raster Calculator* geoprocessing tool, where each odd-number indicating a separate scenario can be added together. For example, during the worst-case scenario, all of the land area inundated under the best-case scenario would also be under water and is added in the worst-case scenario's calculation, which, in turn, is included in the most extreme storm surge scenario's calculation. The attribute table used for these calculations is shown in table 1, found in Appendix A, and is mapped in Map 2. Lastly, the inundated land area is calculated by multiplying the cell count by cell area in m2.

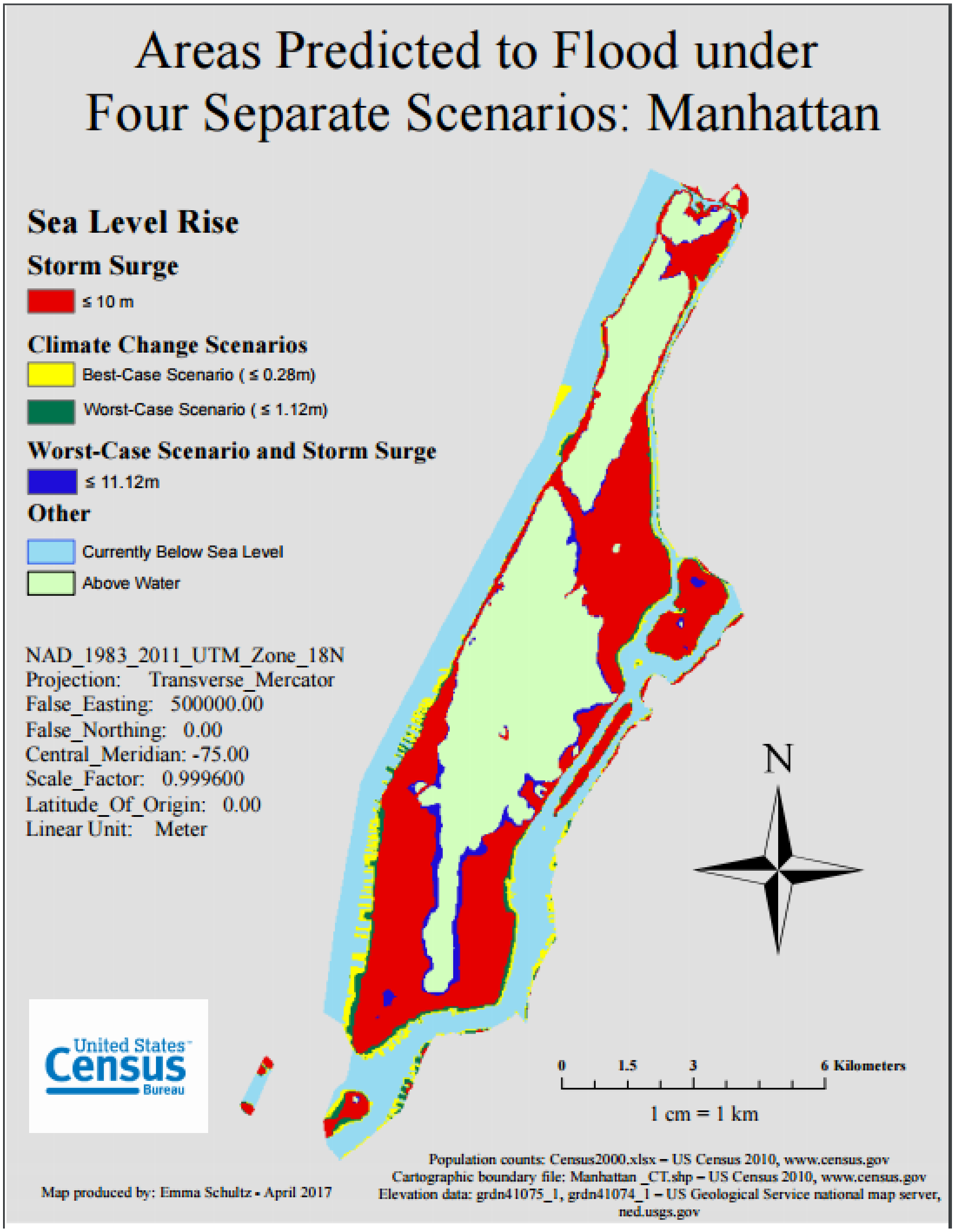
Lastly, the population at risk was calculated by using the population density per m2 for each respective year. Each year's attributes were represented in two separate files, and were converted to a raster grid with the *Feature to Raster* tool. The population and flood data were then overlaid using the *Raster Calculator*. The resultant output files included one for each scenario, which used information from the output raster file previously calculated with all of the scenarios included, was then multiplied by the data from the population density raster files, divided by each scenario's odd-number identifier. The final step used each scenario's attribute table to calculate the total number of people inundated by multiplying the number of people per inundated raster cell. Visual representations are shown for the year 2000 in Map 3, and the year 2100 in Map 4.

Following these GIS methods, it was possible to answer the research questions. The final results are shown in Table 2, indicating the amount of inundated land and the subsequent number of people at risk for each scenario. Figure 2 and figure 3 can be found in Appendix A, which display the ratio of inundated people and land. The scenarios range from around 5.7% of the total land area and 1.2% of the total land area lost from a 0.28m increase, to a staggering 57% of total land area and 48% of the population displaced during a 10m storm surge in conjunction with the worst-case scenario for the year 2100. Therefore, 1.8 million people would be displaced by a storm of that magnitude, which is expected every 75 years (Calef). It was surprising that only 2.5% of the population would be displaced under the projected worst-case scenario climate change model, however, this does still represent over 100 thousand people. Many people, including the current President of the United States, do not believe that climate change is an imperative issue. Attitudes such as these should press planners to expect the worst-case climate scenario. Moreover, work such as this GIS spatial analysis should be updated when climate scientists bring new information to light on how our world is being impacted.

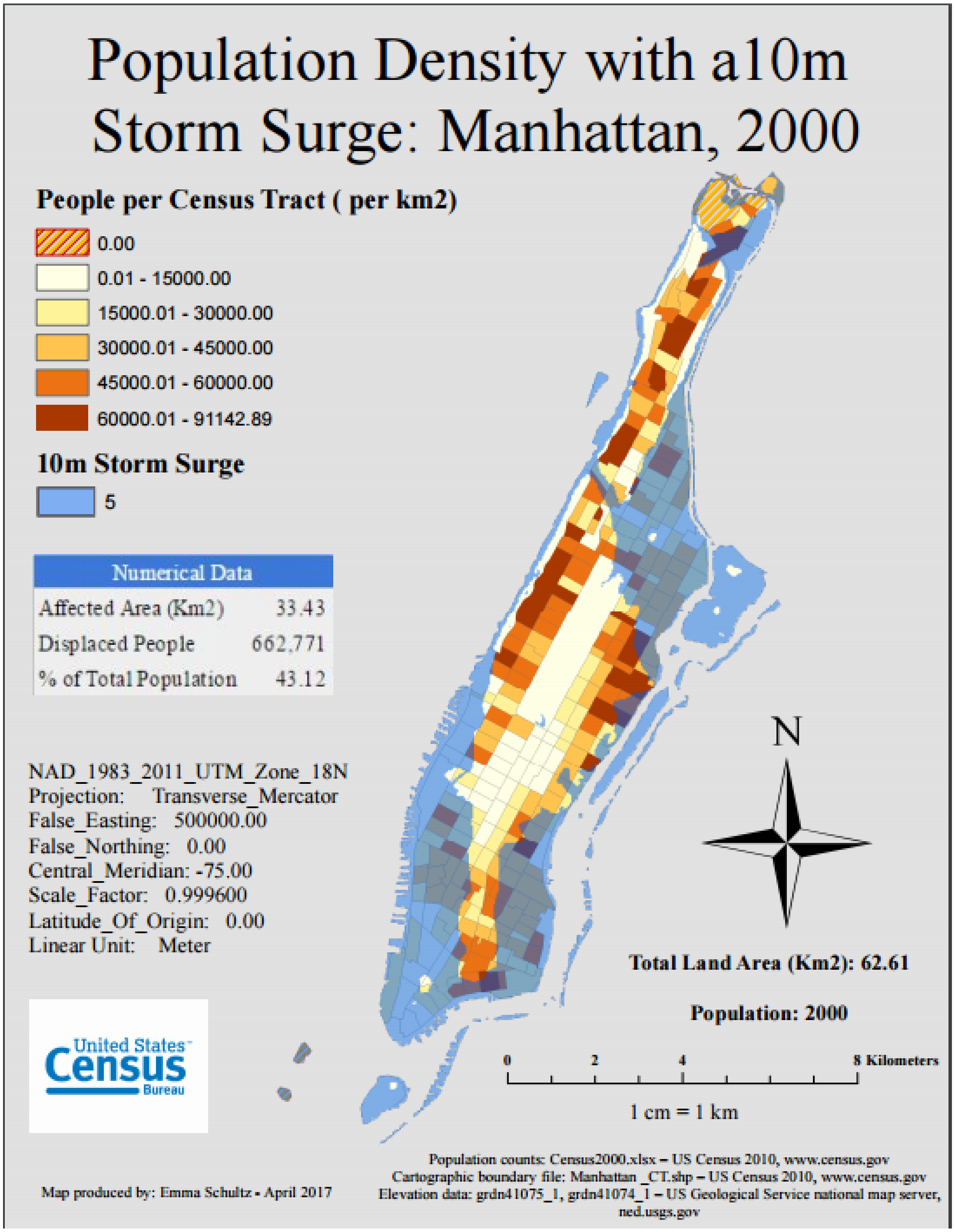
Map 1: Study Area in relation to New York City, including landmass and population characteristics



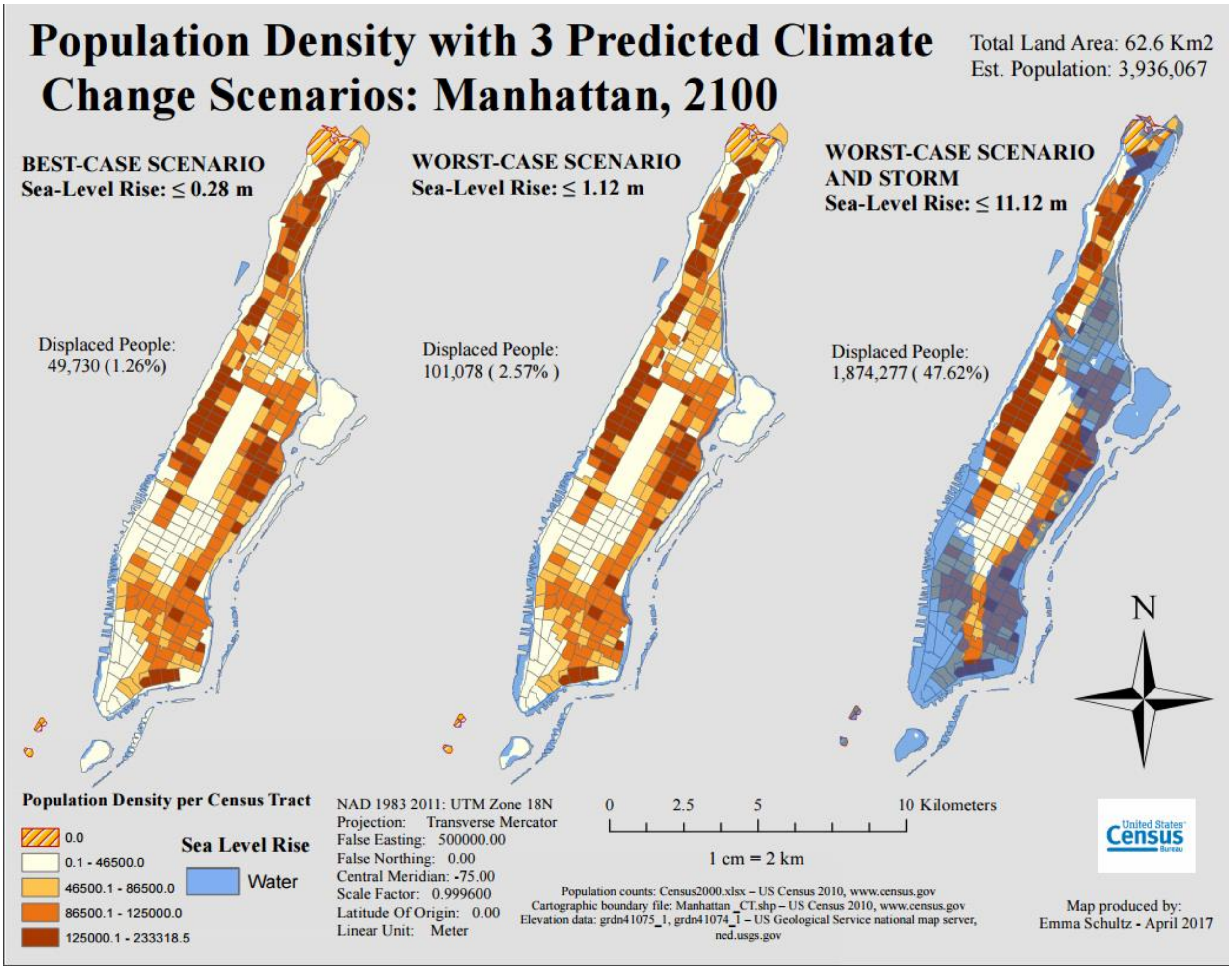
Map 2: Inundation of land area under four scenarios



Map 3: Manhattan's population density with hurricane scenario:



Map 4: Predictions for the year 2100



Appendix A

Figure 1: Historic population growth in Manhattan (green line and triangles) and predicted population growth until 2100 (blue line and squares) based on a second order polynomial model (black line). (ESRI, Calef)

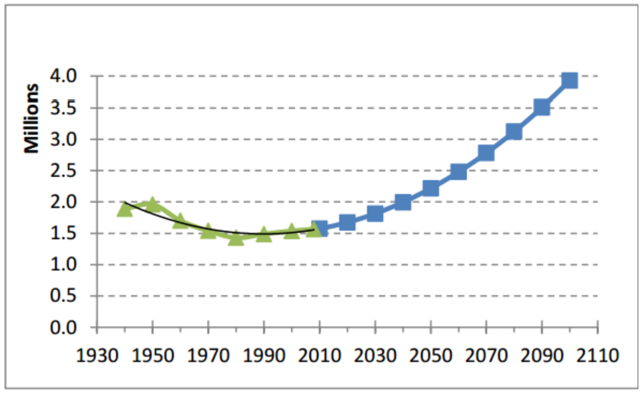


Table 1: Attribute table of the final grid using the raster calculator: all scenarios

SCENARIO	Water levels	VALUE,N,10,0	COUNT,N,10,0	Area (m2)	Total (m2)
currently below sea level	≤ 0 m	0	25604	23,043,600.00	20,739,240,000.00
dry land for all scenarios	> 10 m	7	29869	26,882,100.00	24,193,890,000.00
Worst-Case Scenario and Storm surge	≤ 11.12 m	16	2553	2,297,700.00	35,728,200.00
land flooded under Storm Surge	≤ 10.0 m	21	30435	27,391,500.00	33,430,500.00
land flooded under worst-case scenario	≤ 1.12 m	24	2733	2,459,700.00	6,039,000.00
Floded under All Scenarios (BCS)	≤ 0.28 m	25	3977	3,579,300.00	3,579,300.00

Figure 3: Percent of land lost for each scenario

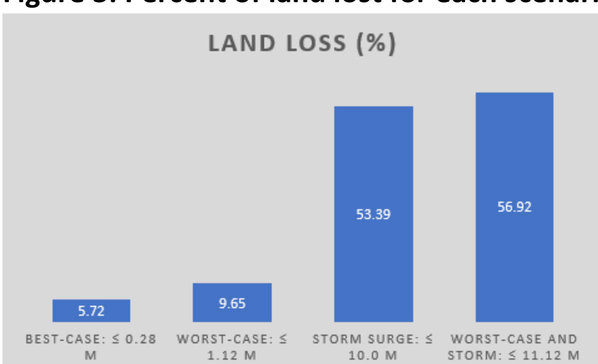
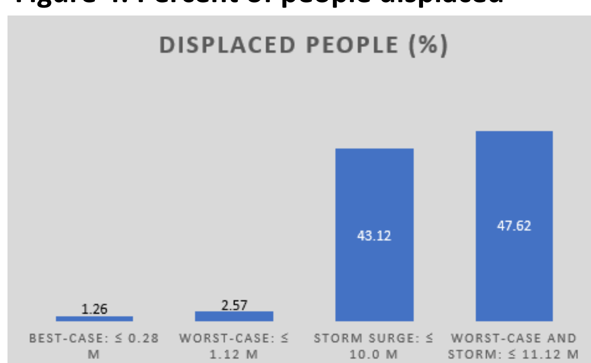


Figure 4: Percent of people displaced



References

Calef, Monica. (2014) Population Mapping and Modeling for Manhattan, Impacts of Sea Level Rise and Storms on Manhattan, People of Manhattan at Risk. New York, NY: ESRI Spatial Labs.

Horton, R., Little, C., Gornitz, V., Bader, D. and Oppenheimer, M. (2015), New York City Panel on Climate Change 2015 Report Chapter 2: Sea Level Rise and Coastal Storms. Ann. N.Y. Acad. Sci., 1336: 36–44

Meehl, G. A., et al. "Global Climate Projections," in Climate Change 2007: The Physical ScienceBasis. Contribution of Working Group I to the Fourth Assessment Report of theIntergovernmental Panel on Climate Change, edited by Solomon, S., D. Qin, M. Manning, Z.Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge, UK, and New York, NY: Cambridge University Press, 2007.

Data sets

Population counts: Census2000.xlsx – US Census 2010, www.census.gov

Cartographic boundary file: Manhattan _CT.shp – US Census 2010, www.census.gov

Elevation data: grdn41075_1, grdn41074_1 – US Geological Service national map server,

Ned.usgs.gov

New York Counties boundary file: NY_counties_clip.shp -

https://www.arcgis.com/home/item.html?id=7f4850fb7d18496ca6925f209d2d1275

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Calef, Monica: Population Mapping and Modeling for Manhattan, Impacts of Sea Level Rise and Storms on Manhattan, People of Manhattan at Risk.