ASSESSING THE IMPACTS AND EXTENT OF INUNDATION DUE TO SEA LEVEL RISE ON LONG ISLAND, NY

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LIST OF ABBREVIATIONS

Sea Level Rise (SLR)	A product of global warming that describes the average level increase of the world's oceans.
Global Mean Sea Level (GMSL)	Average height of the entirety of the world's oceans.
Digital Elevation Model (DEM)	Raster representation of elevation data.
Geographic Information Systems (GIS)	Computer-based systems used to analyze and visualize geographic data.

ABSTRACT

Sea level rise is a cause of major concern for residents and policymakers of Long Island, New York. Long Island is an immensely populated island located east of New York City. Unfortunately, the island faces massive risk of inundation due to sea level rise. This inundation is a direct result of climate change. At its current pace, sea level rise will cause the uprooting of lives and communities for the next generation of Long Island residents. Even for the current generation, sea level rise poses a sizeable risk to many. This project employs a multitude of geoprocessing and analytical tools from ArcGIS Pro to quantify and assess the risk posed to Long Island. This risk is assessed at a sea level rise of 1 foot, and again at a rise of 4 feet. These two levels are consistent with studies that suggest these levels are realistic values to project for Long Island by the year 2100. This is with one foot being the probable minimum and four feet being the maximum. Additionally, this project utilizes census data for delving into exactly which communities are most at risk, in terms of demographic and income. It is evident that if changes are not made in an attempt to mitigate climate change, Long Island and its wealth of communities and demographics will face devastation. Many homes will be destroyed or completely underwater, shorelines will continue to move inland, and a number of different demographics that reside on Long Island will be deracinated.

Keywords: Sea Level Rise, Long Island, Inundation, Risk, Climate Change

ETHICS STATEMENT

Those who utilize the many powerful technologies of Geographic Information Systems (GIS) are responsible for heeding a code of ethics. In turn, this code is responsible for promoting the trust and reliability of not only GIS, but the user as well. Maps serve as an invaluable tool for society, and thus, the results of GIS tend to be believed. The primary theme within this code is to understand your obligations as a GIS professional. As someone who utilizes GIS in a professional setting, you are responsible for recognizing your obligation to all involved. This may include your employer, colleagues, or society as whole. When faced with a dilemma, a GIS professional must review the morality of the situation and recognize to whom they owe their obligations. These obligations will be tested by a multitude of ethical issues that surround GIS practice today. These issues include providing accurate information, as well as properly citing the work of others. Lastly, and perhaps most importantly, it is paramount for a GIS professional to respect the privacy and autonomy of others. Understanding the repercussions and/or benefits of your work on an individual or group of people is part of practicing GIS.

For this project in particular, it was important for me to understand the obligation that I have to those who inhabit Long Island. Not only was it important for me to analyze the effect of sea level rise on Long Island as a whole, but also for me to dissect how it would affect different demographics. Some demographics will not have the same resiliency in the face of adversity, and this was made apparent in this project. By doing so, I am fulfilling my obligation to residents of Long Island and to the different communities within. Additionally, there are a great deal of datasets and pieces of

information that were gathered from external sources and used to support my project. By using these, I have an obligation to check the accuracy of these sources and cite them and give full credit to the author(s) of each dataset or article. This ethical challenge was solved, and my project now meets ethical expectations by reviewing all obligations and following the GIS code of ethics.

CHAPTER 1
INTRODUCTION

The single largest concern our planet faces today is climate change. Climate change is directly responsible for an abundance of detriments to the Earth. These detriments include intense storms, extreme temperatures, and the loss of animal species. While these are all devastating to humankind, one of the greatest threats to the human race posed by climate change is sea level rise (SLR). SLR is especially harmful to coastal communities and can completely uproot lives and communities as a whole. SLR is linked to climate change because extreme changes in temperature melt glaciers and ice sheets. Once these glaciers melt, the volume of water in the ocean increases. It is estimated that Greenland is losing 280 billion tons of ice every year. Similarly, Antarctica is losing about 150 billion tons of ice a year (Masterson 2022). These two areas are most responsible for sea level rise. Additionally, when water becomes warm it "expands slightly" (EPA 2022). Though, when faced with a massive body of water like our oceans, this small expansion makes a large difference.

While there are a multitude of ways to mitigate this concern, daily human activities have induced this climate change to a rate that has never been seen before. Human activities are responsible for greenhouse gas emissions in the atmosphere. The top contributor to these greenhouse gas emissions is energy use. Key examples include energy use in industry, transportation, and in buildings (Richie et al. 2020). The major greenhouse gases that result from this use of energy are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and industrial gases (EIA 2022). These greenhouse gases absorb radiation from sunlight and trap heat in the earth's atmosphere, which results in climate change and ultimately, sea level rise. This is

happening at an exceeding rate, which is exacerbating the effects of climate change with each passing decade.

Since 1900, the Global Mean Sea Level (GMSL) has increased by about 7-8 inches. To put the rate in perspective, three of those inches have come since 1993 (Sweet et al. 2017). Between 2017 and 2030, it is expected that GMSL will have risen 4-8 more inches and will continue to rise between 1-4 feet by 2100, depending on actions taken to lessen the blow of climate change. Disturbingly, it is physically possible that a GMSL rise of over 8 feet is possible by 2100, though, this is of extremely low probability. GMSL increase also leads to an increased number of tidal floods, which have been harming coastal communities at an alarming rate. Additionally, this will worsen the effects of natural disasters and extreme weather events because flooding will also become more extreme. Of course, SLR will vary from coastline to coastline throughout the United States. This is due to “changes in Earth’s gravitational field and rotation from melting of land ice, changes in ocean circulation, and vertical land motion” (Sweet et al. 2017). It is estimated that up to 410 million people could be “vulnerable” to rising sea levels by the end of the 21st century (Whiting 2022). This estimation is based on the idea that by the century’s end, 410 million people could be living on land less than 2 meters above sea level, putting them at great danger of inundation. The Organization for Economic Co-operation and Development (OECD) estimates that damages from worldwide sea level rise could cost as much as $5.5 trillion in this timeframe (Whiting 2022).

A largely populated area with diverse communities that is in great danger of inundation due to sea level rise is Long Island, New York. Long Island is an island east

of New York City that is about 120 miles in length, and 23 miles in maximum width (NYWSC 2017). It is comprised of four counties: Kings, Queens, Nassau, and Suffolk. As of 2018, minorities make up over one third of the Long Island population. This is a 10% increase over the last two decades (Metzler 2019). This proves that there are a variety of communities and demographics at risk when it comes to inundation on Long Island.

Long Island has a population of over 8 million people, which is over a third of the total New York population. New York's population, as of 2020, sits at around 20 million people. This is a 4.1% population increase over the last decade (NYS Comptroller 2021). Long Island, which is located just south of Connecticut, is home to four barrier islands that slightly protect Long Island from the Atlantic Ocean. These barrier islands are Long Beach, Fire Island, Jones Beach, and Westhampton Beach. These barrier islands, which are populated, are in extreme danger of flooding due to sea level rise. Even with these barrier islands, the south shore of Long Island is known to be an area of great concern, with most of it being just around five foot above sea level (Jaquez 2022). Of the four counties, it is likely that Suffolk County would see the most damage due to its long coastlines. Suffolk is also the largest in area of the four counties, though it has a lower population than Kings and Queens counties. Figure 1-1 displays the four counties that comprise Long Island, and the location of Long Island relative to the area.

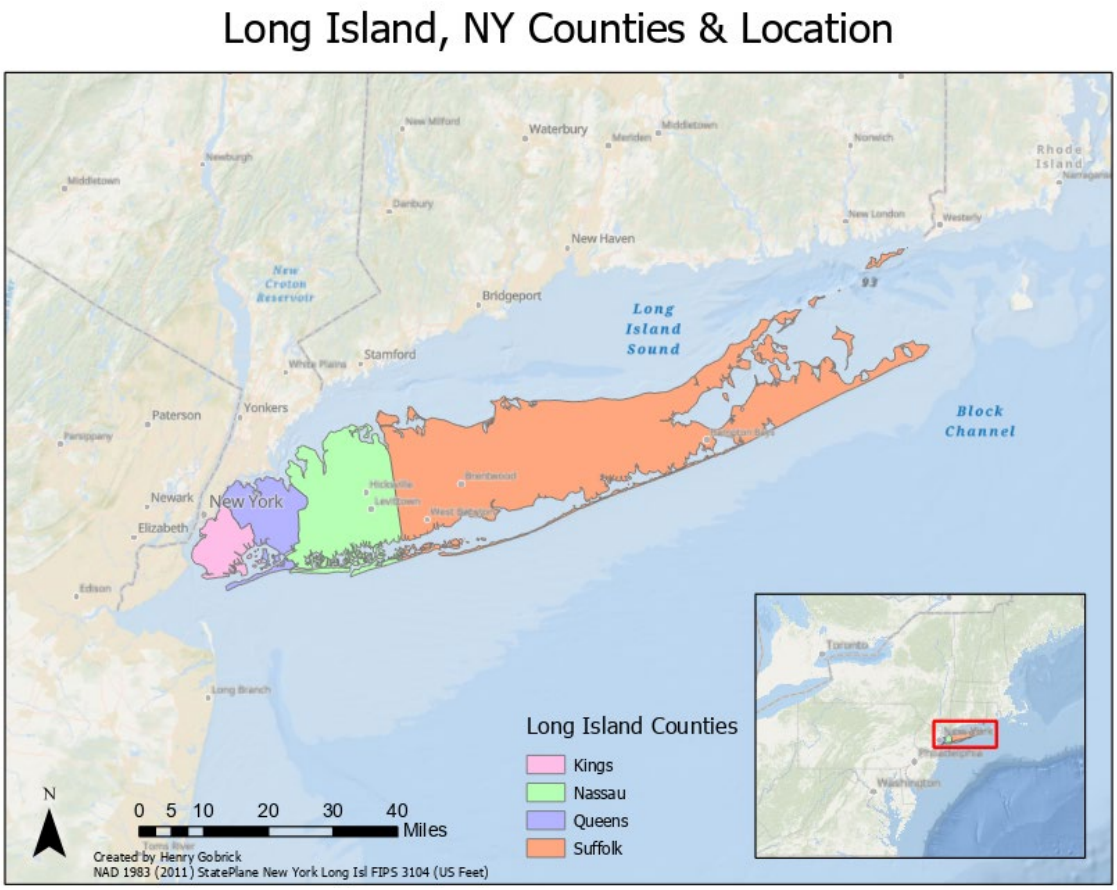

Figure 1-1. Map of Long Island's four counties and the location of Long Island relative to the tri-state area.

Since 1880, there has been an average global sea level rise increase of about 8 inches. In New York state, the sea level increase has almost doubled the global average, at around 13 inches of rise since 1880 (Gonzales 2021). For Long Island, the National Oceanic and Atmospheric Administration (NOAA) currently projects a 4 foot sea level rise by 2100 (Gonzales 2021). This proves that climate change, and specifically sea level rise, is not something that can be ignored for future generations to contend with. The United Nations claims that the world needs to eliminate 45 percent of its carbon emissions by 2030 (Lieberman 2022). This is an issue that must be solved

and mitigated in the next few years before it becomes irreversible. The United Nations has expressed serious concerns that climate change, in its current state, may already be irreversible (Lieberman 2022).

While this issue is pressing for the entirety of the world, Long Island faces massive risk of inundation. While the population of Long Island continues to boom, so does the risk involved with living on its beautiful coastlines. The goal of this project is to analyze how immense this risk is, and which communities and demographics will be affected most. Based on NOAA's projections for Long Island and how quickly the sea level has been rising, sea level rises of 1 foot and 4 feet will be quantified in this project. These levels are both projected to hit Long Island by 2100. While studies exist that signal danger for Long Island due to climate change, the objective of this project will be to scrutinize and investigate the threat posed by sea level rise and who the threat will be most harmful to.

CHAPTER 2
METHODS AND DATA

Analysis in this project was done using ArcGIS Pro (version 3.0.3), a powerful desktop GIS software developed by Environmental Systems Research Institute (ESRI) and originally released in 2015. While ArcGIS Pro was released in 2015, ESRI mapping products have been around since the early 1980's. All datasets utilized in this project were downloaded and then uploaded to ArcGIS Pro for proper application and analysis. All datasets were clipped to my study area of Long Island, NY and projected to the "NAD 1983 (2011) StatePlane New York Long Isl FIPS 3104 (US Feet)" projection system. These two processes were done using two ArcGIS Pro geoprocessing tools: Clip and Project. Additionally, other geoprocessing tools like Intersect will be employed for visualization of how much land will become inundated in the event of each sea level rise increment. For this project, increments of 1 foot and 4 feet will be used. These increments align with studies that show a threat to the current generation. A variety of shapefiles and feature classes were utilized to develop my analysis. Figure 2-1 shows the general workflow for the analysis done in this project.

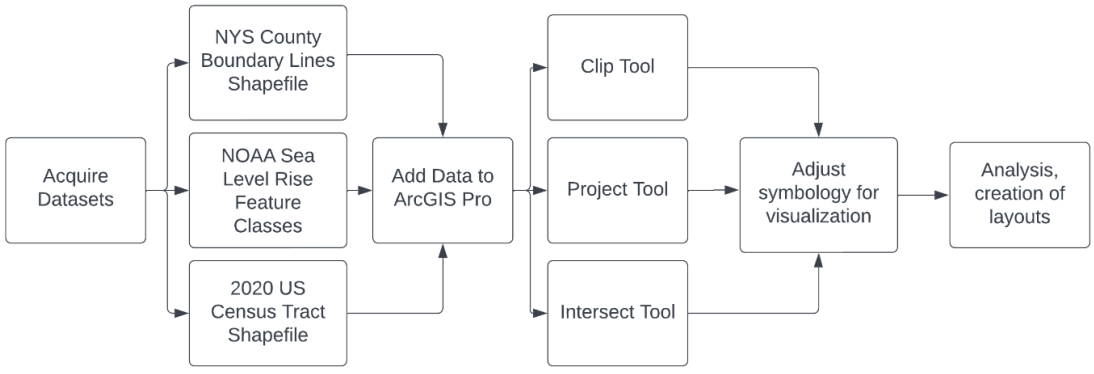

Figure 2-1. Simplified workflow diagram

In order to visualize and understand my study area, I first sought out a dataset for New York State County boundaries. I was able to find these boundaries easily on the New York State website in a dataset of shapefiles titled “NYS Civil Boundaries”. Figure 2-2 depicts the data found in this dataset.

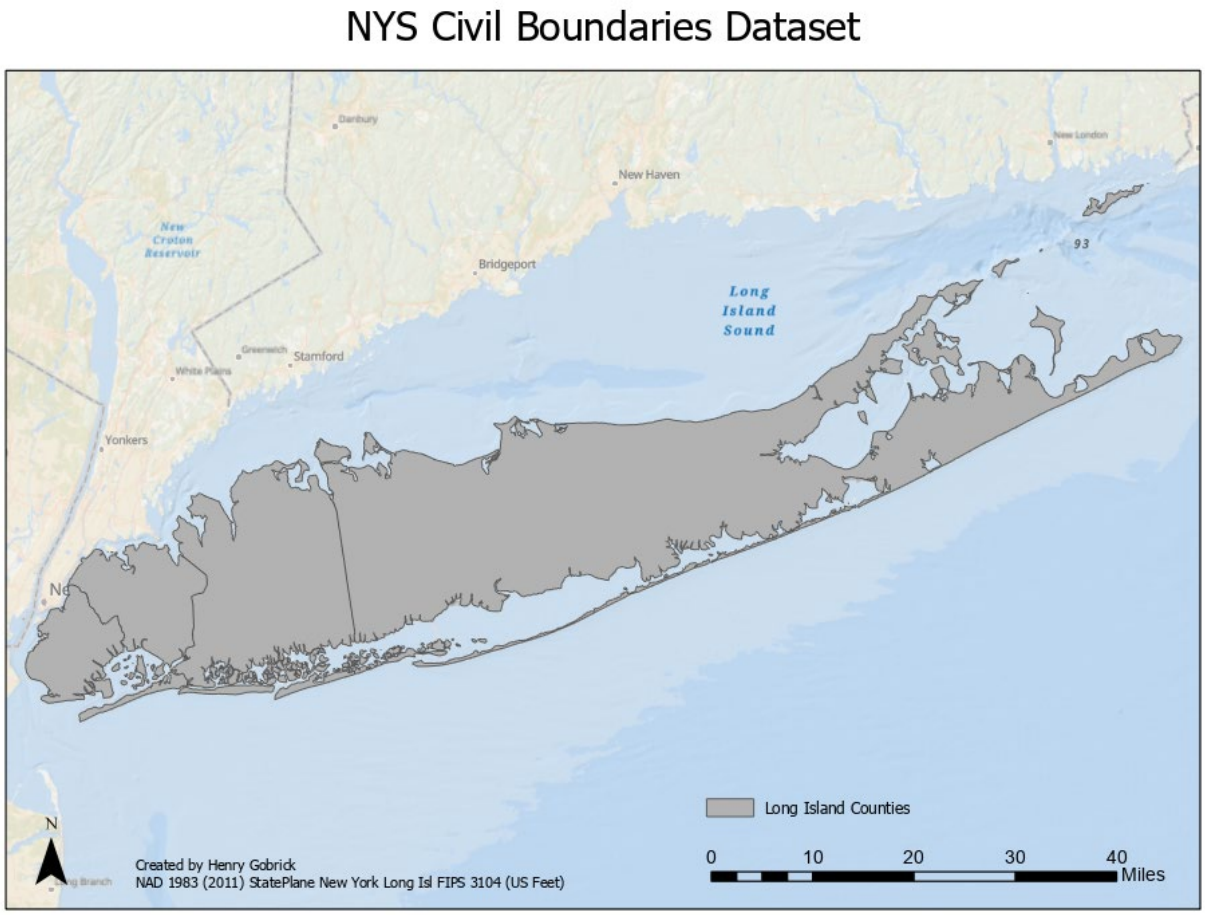

Figure 2-2. NYS Civil Boundaries Dataset

Table 2-1. NYS Civil Boundaries Metadata

Official name of data set	NYS Civil Boundaries (includes NYS County Boundaries – Shoreline Version)
Year of publication and/or last update	2022
Author and/or owner	New York State GIS
URL of repository	https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=927
Description	Shapefile for boundaries of NYS Counties
Coordinate System	NAD 1983 UTM Zone 18N
Projection	Transverse Mercator
Spatial Resolution or Geometry Type	Polygon

Once I had my boundaries, I needed to gather my census data. I will be using this data to depict which communities and demographics are most at risk of inundation due to sea level rise. This dataset, titled “American Community Survey 5-Year Estimates” came in the form of a geodatabase comprised of tables and one feature class. The feature class, titled “ACS_2020_5YR_TRACT_36” is polygon census data that gives numerical statistics for race, gender, and age group populations for each census tract in New York State. This data is depicted in Figure 2-3.

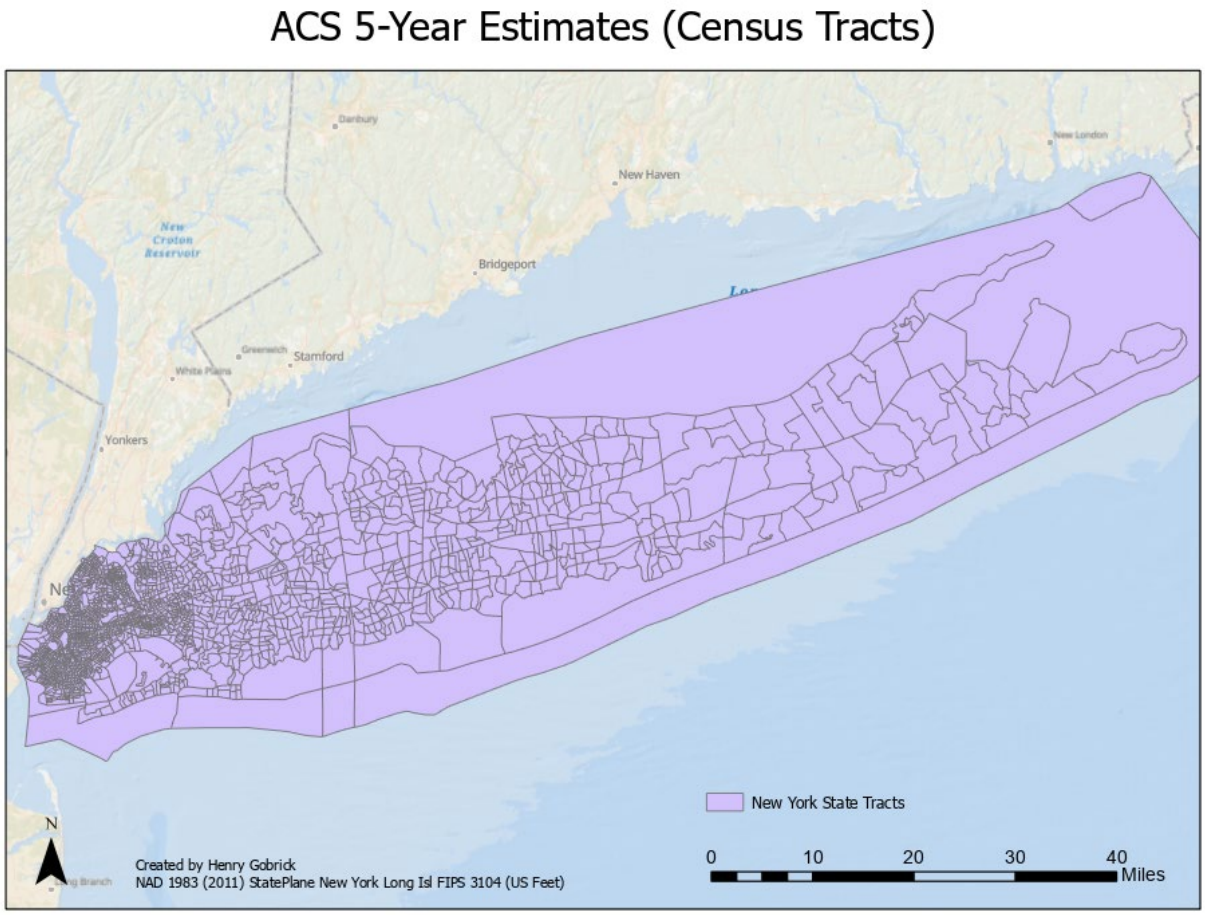

Figure 2-3. Census data polygons for Long Island, depicted by tract

Table 2-2. American Community Survey 5-Year Estimates Metadata

Official name of data set	American Community Survey 5-Year Estimates
Year of publication and/or last update	2020
Author and/or owner	US Census Bureau
URL of repository	https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-data.html
Description	Geodatabase for NY Census Data
Coordinate System	NAD 1983 UTM Zone 18N
Projection	N/A
Spatial Resolution or Geometry Type	Polygon

Lastly, and most importantly, I needed to find data that could help depict sea level rise on Long Island at different increments. My original thought was to use digital elevation models (DEMs) to show at which sea level each part of Long Island would begin to see inundation. Fortunately, NOAA has an entire database of sea level rise shape files that portray the effect of sea level rise at increments from 1 to 10 feet. This was an incredibly useful dataset that will allow me to show exactly what detrimental effects different sea level rise increments will have on Long Island. Figures 2-4 and 2-5 illustrate this data for increments of 1 foot and 4 feet, respectively.

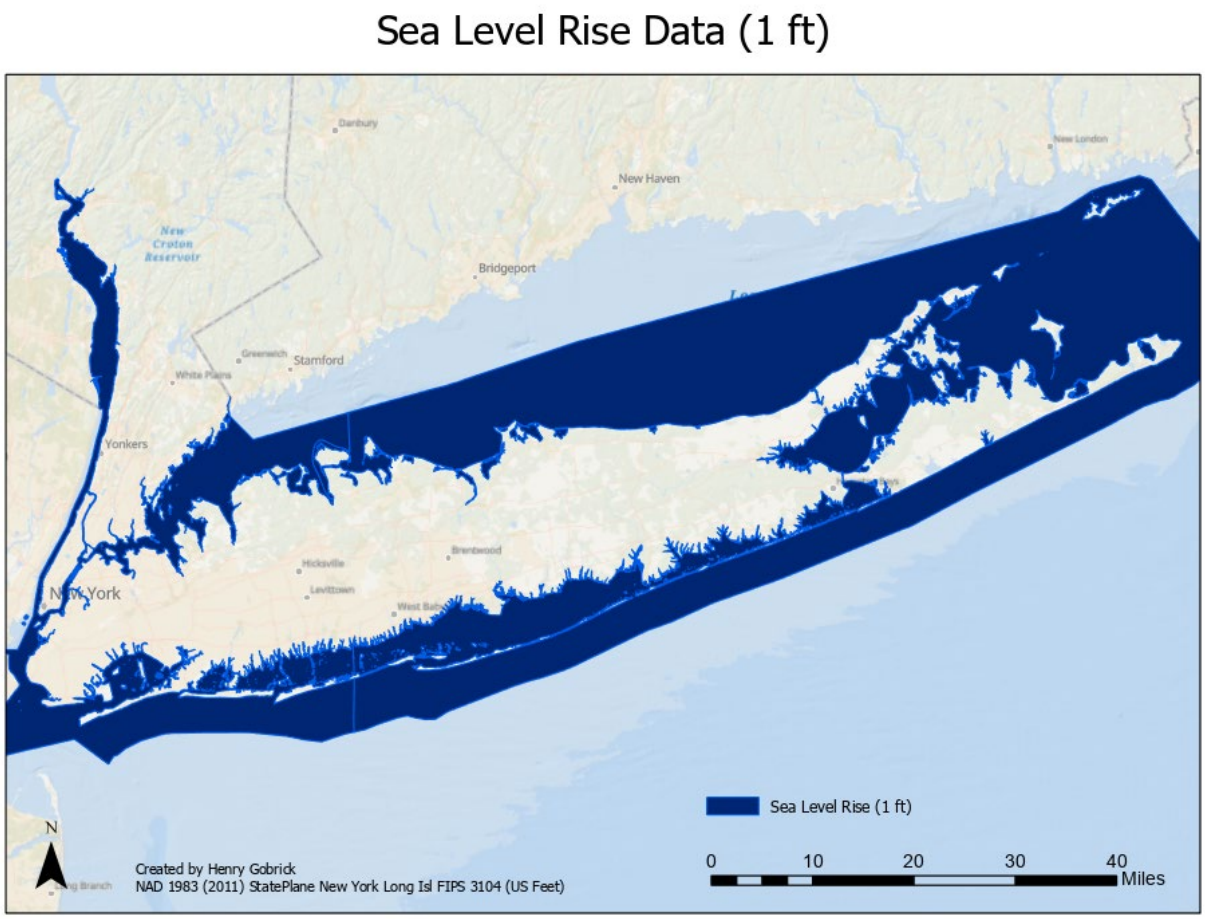

Figure 2-4. Sea Level Rise Data for 1 ft SLR

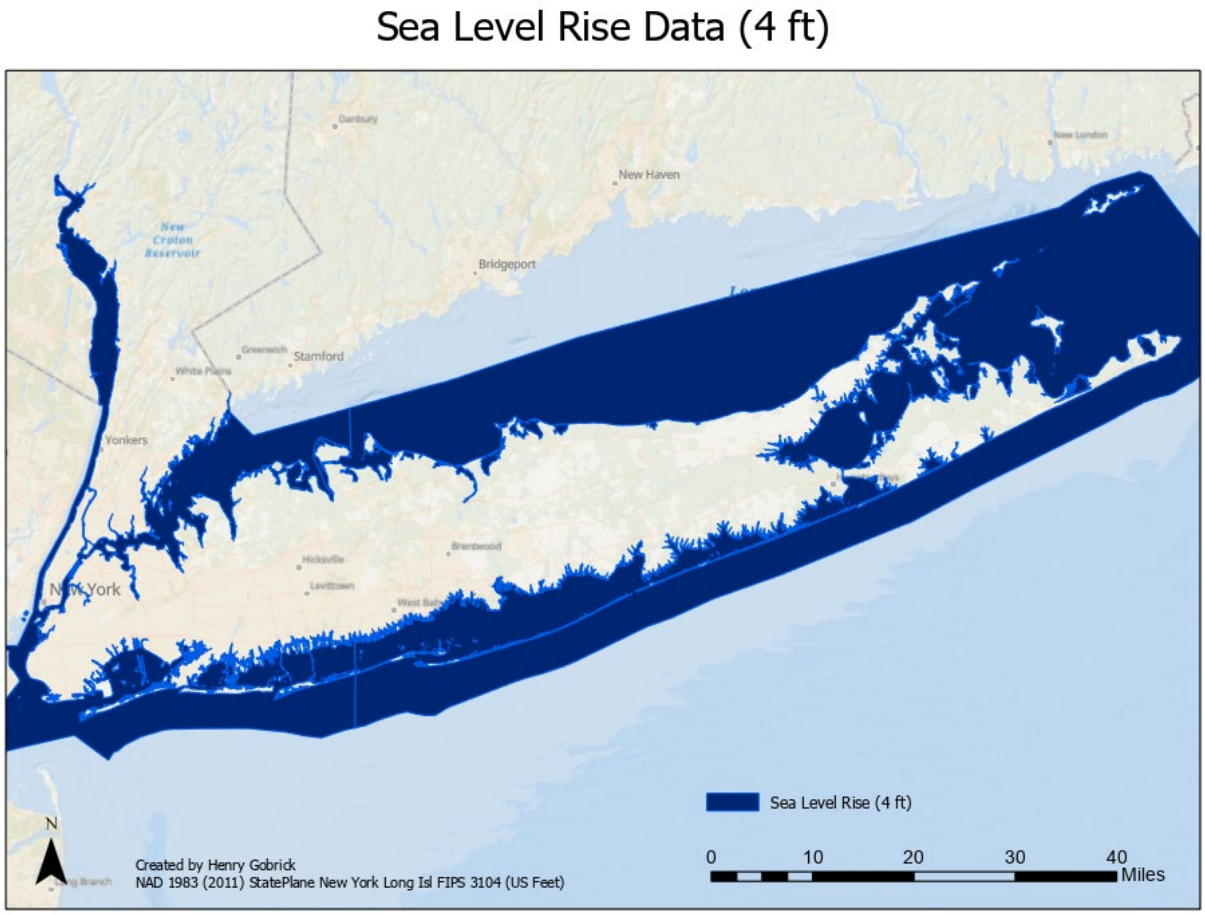

Figure 2-5. Sea Level Rise Data for 4 ft SLR

Table 2-3. Sea Level Rise Data Metadata

Official name of data set	Sea Level Rise Data
Year of publication and/or last update	2022
Author and/or owner	NOAA
URL of repository	https://coast.noaa.gov/slrdata/
Description	Database for Sea Level Rise at increments 1-10 ft
Coordinate System	NAD 1983
Projection	N/A
Spatial Resolution or Geometry Type	Polygon

These datasets will be utilized to measure the effect that sea level rise will have on two distinct populations: households making less income than the Long Island average, and minorities. The average household income on Long Island is $103,041 as of 2019 (Forbes 2019). To be precise, I utilize the census data to portray the percentage of households making less than $100,000. To portray the minority population on Long Island, I calculate the non-white population. This is done by adding together the population of all non-white population fields and dividing by the total population for each tract. With these populations calculated, I can investigate the effect that sea level rise will have on each.

CHAPTER 3
RESULTS

The first feature class created in ArcGIS Pro for this analysis was to depict household income. With the average household income on Long Island being just barely over $100,000, this feature class is titled “Household income < $100,000”. This depicts the percentage (by tract) of those making less than $100,000 on Long Island. This is depicted by percentage and displayed with a ramped graduated color symbology in Figure 3-1.

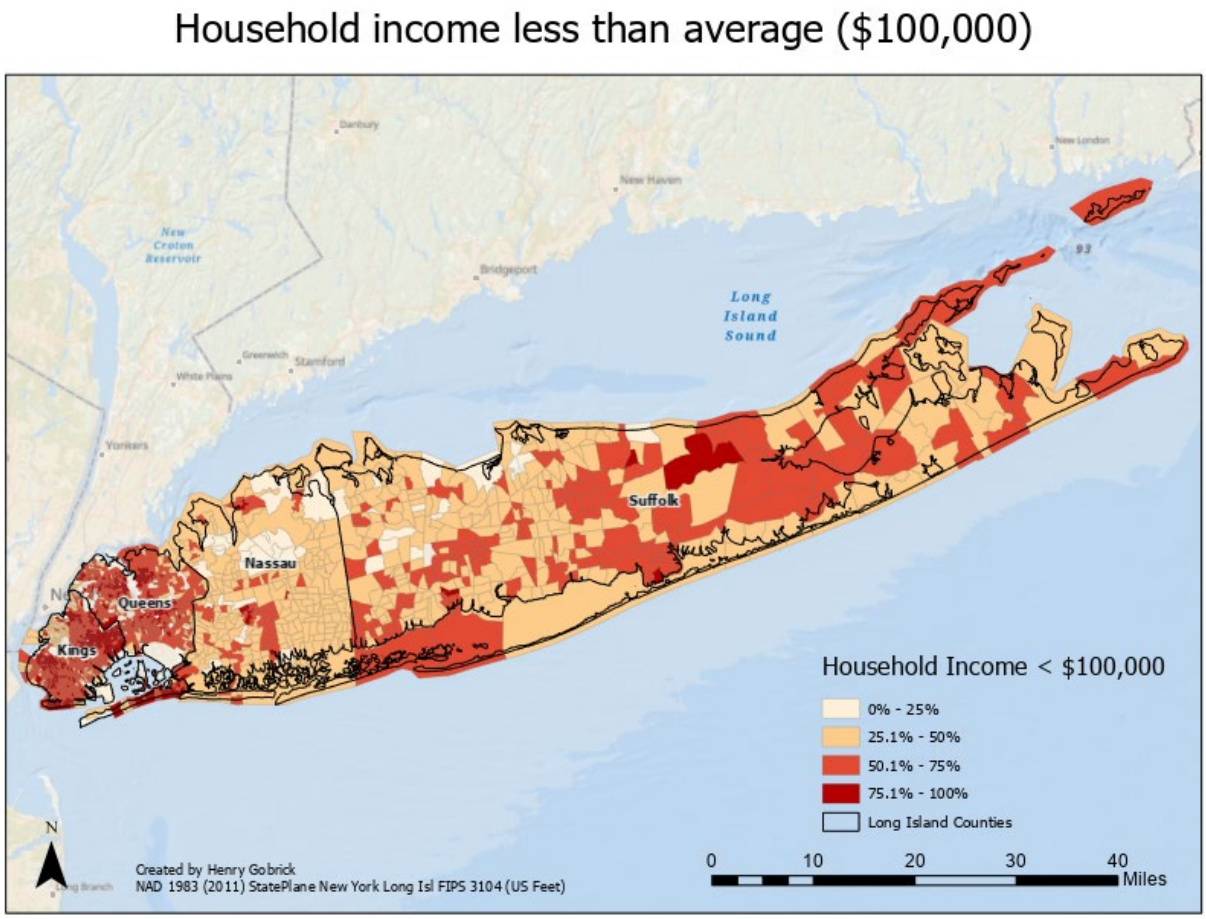

Figure 3-1. Percent household income less than average on Long Island by census tract

It is evident that while Long Island is a generally affluent area, plenty of areas are densely populated with households that make less than $100,000 in total household income. Of the 2,124 census tracts on Long Island, only 667 tracts had more than half of its households making over the Long Island average income. In other words, only a lowly 31.4% of census tracts on Long Island have more than half of its households making above average income. This is particularly apparent in Kings and Queens counties, where both of which contain an immense number of tracts below the average household income for the island. For Kings County, only 15.5% of tracts are above the Long Island average. For Queens County, this number is only 14.3%. The data suggests that Queens and Kings counties are especially struggling. This is depicted by the darker red coloring in Figure 3-1. However, income does not tell the full tale of a demographic scope. The second feature class created to analyze affected demographic is non-white population. Similar to household income, this is expressed as a percentage. This feature class is depicted in Figure 3-2.

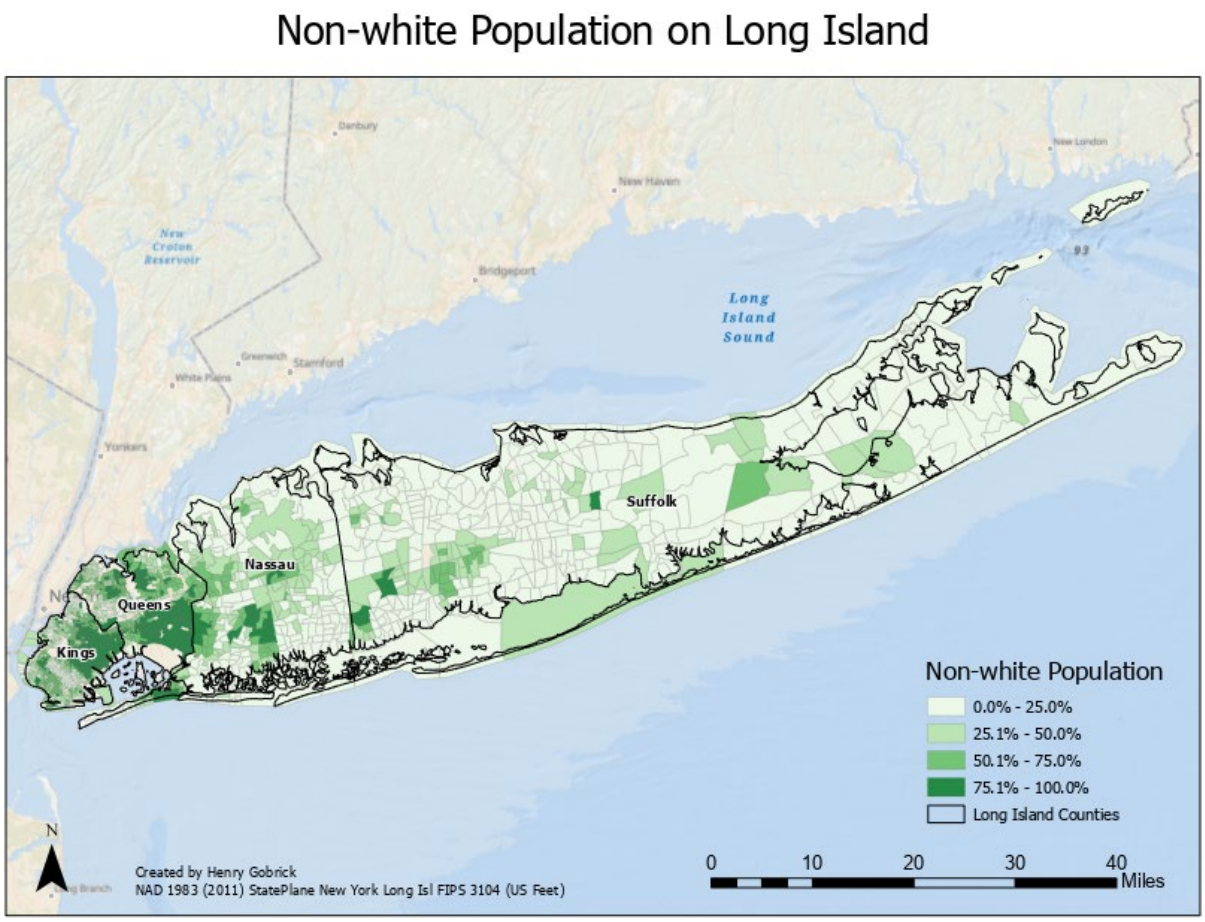

Figure 3-2. Percent non-white population on Long Island by census tract

This figure demonstrates that while there is an existing minority population on Long Island, the bulk of it appears to be to the west. In fact, 48% of the census tracts on Long Island have a non-white population above 50%. This percentage is anchored heavily by Kings and Queens counties, with a large number of their tracts seeing a minority population of over 75%. 1,463 of the 2,124 tracts on Long Island are located within Kings and Queens counties, indicating that these are the most densely populated areas on Long Island. 58.6% of tracts in Kings County sport a majority non-white population, while Queens County has this number at 67.2%. It is vital to the study to

analyze how sea level rise will affect the low income and minority populations in addition to the island as whole because of the way they are equipped to handle a potential catastrophic inundation. Sea level rise and its potential devastation will only exacerbate underlying issues that lie within certain demographics. Consistently, minorities struggle with relocation, food security, and other socio-economic issues (Haider et al 2021). It is worth noting that these issues that become exacerbated by sea level rise are generally a consequence of poor decision making by policymakers over the course of decades. Minorities historically have not been allowed the same economic mobility as others, and that marginalization is still seen in some communities to this day. While this may not exactly be the case with Long Island, minorities will struggle with sea level rise to a greater degree in just about any region. While a great deal of this struggle boils down to income, it is not the only factor. For the entirety of Long Island, the intersect tool within ArcGIS Pro was used. Intersect was used to find the areas where sea level rise overlaps the four counties that make up Long Island. This tool was run twice, for sea level rise increments of 1 foot and 4 feet. Both results are displayed in Figure 3-3.

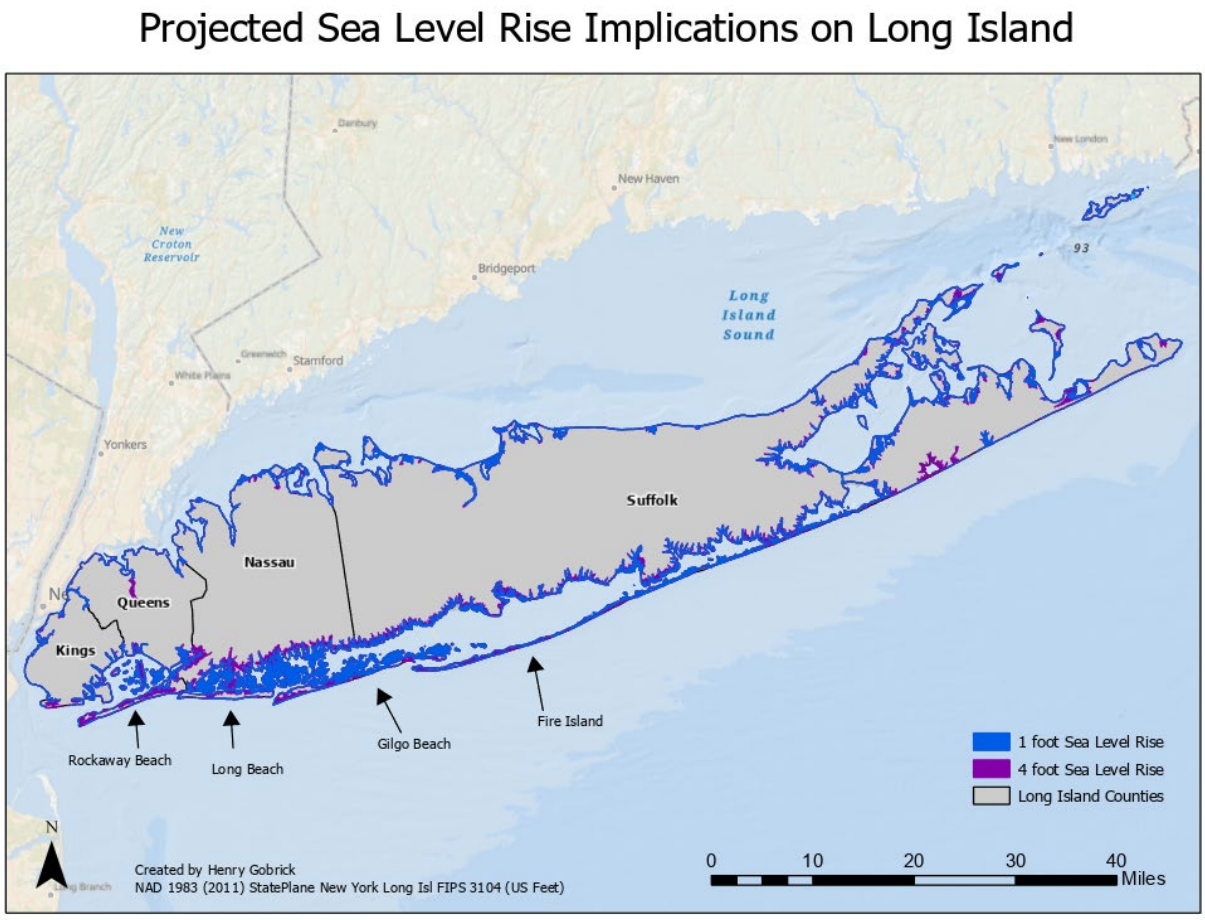

Figure 3-3. The implications of 1ft and 4ft SLR on Long Island

As made apparent by Figure 3-3, Long Island will see a large amount of flooding and likely destruction on both the north and south shores. While the flooding will generally be consistent throughout the island, some areas will certainly see the worst of it. Perhaps the area of most concern is along the barrier islands and beaches on the south shore of Long Island. With just a sea level rise of one foot, the water level will be greater than the elevation of the entirety of Fire Island. Fire Island is home to thousands of people. Though some of these residents are seasonal, their homes will be completely decimated. This applies on a larger scale for any building along any of Long Island's shores. On Long Island, just about every shore is packed with homes, restaurants, and

office buildings. A lot of them will see damage or complete destruction in the event of a sea level rise of even one foot. Using ArcGIS Pro and the feature classes depicted in Figure 3-3, it is projected that over 56 square miles of land on Long Island will be underwater in the event of a 1’ SLR. In the event of a 4’ SLR, over 105 square miles of land will be submerged. For reference, Long Island is about 1400 square miles. This means that in the event of a 1’ SLR, 4% of Long Island will be completely inundated. At a 4’ SLR this number nearly doubles, with 7.5% of Long Island inundated. Within these areas are tens of thousands of homes and businesses, all of which will be flooded and destroyed. It is important to understand that some areas on Long Island are more affluent than others and those areas will be more financially resilient in the event of extreme inundation. It is paramount that the demographics are understood when conducting an analysis of sea level rise on a particular area. Figure 3-4 displays the implications that sea level rise will have on Long Island along with the 31.4% of tracts that do not make at least $100,000 in annual income by household.

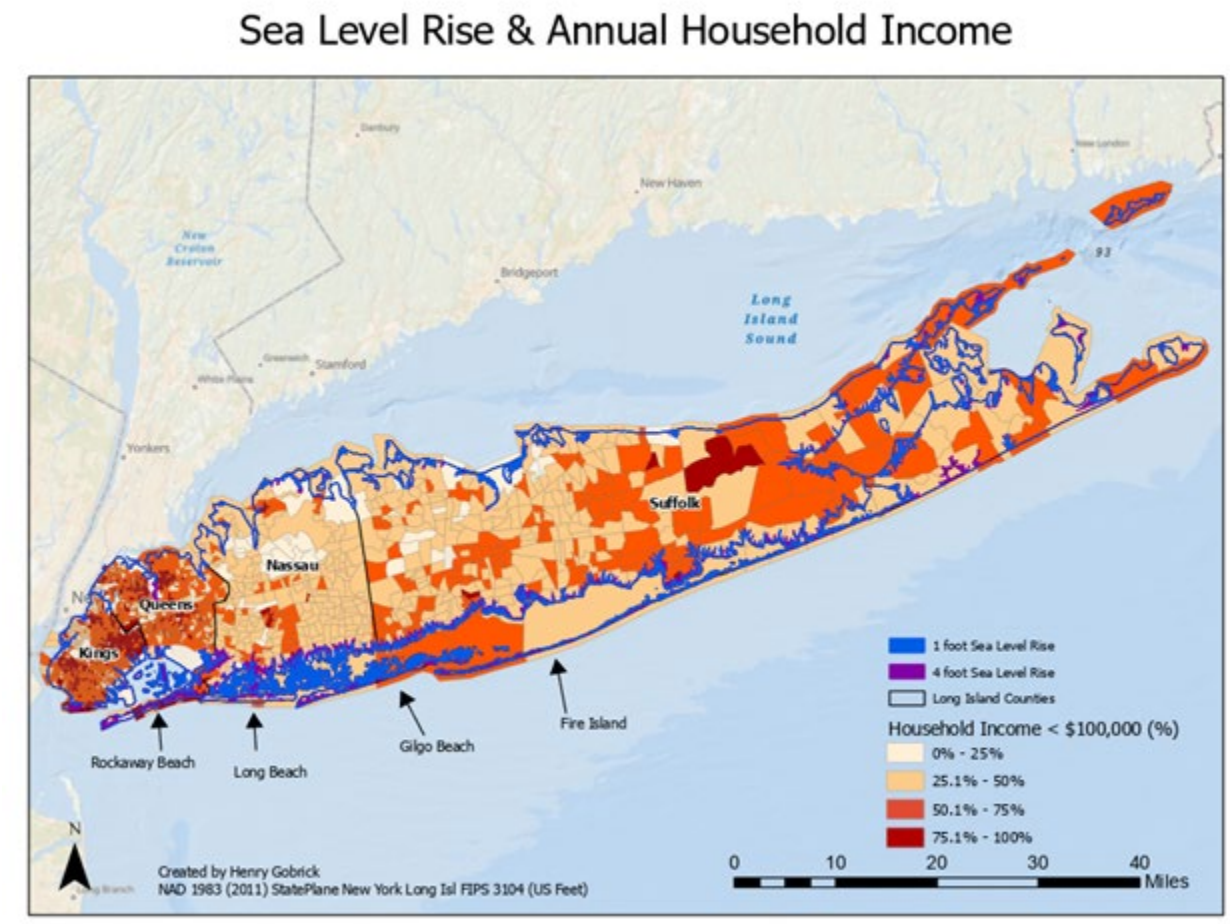

Figure 3-4. Sea level rise & percent annual household income by census tract

Kings and Queens counties, which are struggling most to meet the average household income, will see flooding particularly on their southern border. The Rockaway peninsula (labeled on Figure 3-4) in particular is an area in Queens County that struggles financially, and a sea level rise of 4ft will inundate almost the entire peninsula. Additionally, Long Beach and Gilgo Beach which reside in Nassau County will be decimated. Between these areas, tens of thousands of people will see their homes destroyed and their entire lives uprooted and relocated. While the sea level rise appears to be a consistent issue throughout Long Island, it is clear that both wealthy and

unwealthy communities are in jeopardy. To take demographics into further consideration, Figure 3-5 displays sea level rise over the percentage of non-white population in each census tract. This shows which minority-rich areas will struggle with inundation the most.

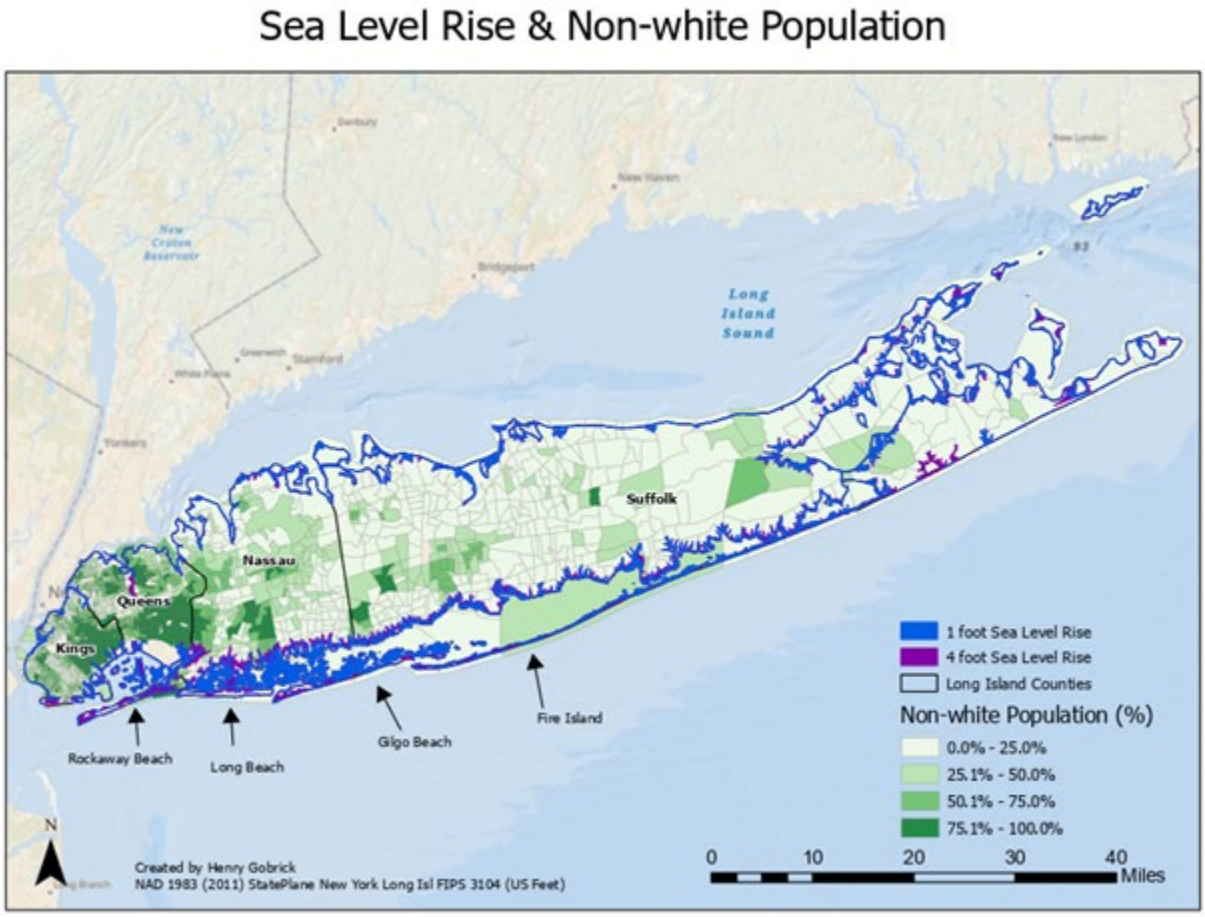

Figure 3-5. Sea level rise & percent non-white population by census tract

Since western Long Island has the largest non-white population and appears to be struggling most with household income, it is important to visualize the impacts of SLR on these areas in particular. Figures 3-6 and 3-7 display the implications of 1 foot and 4 foot sea level rises, respectively. In Figure 3-6, both household income and non-

white population are overlaid by a sea level rise of one foot, colored in transparent blue. In Figure 3-7, the same two demographic factors are overlaid by a sea level rise of four feet, colored in transparent purple.

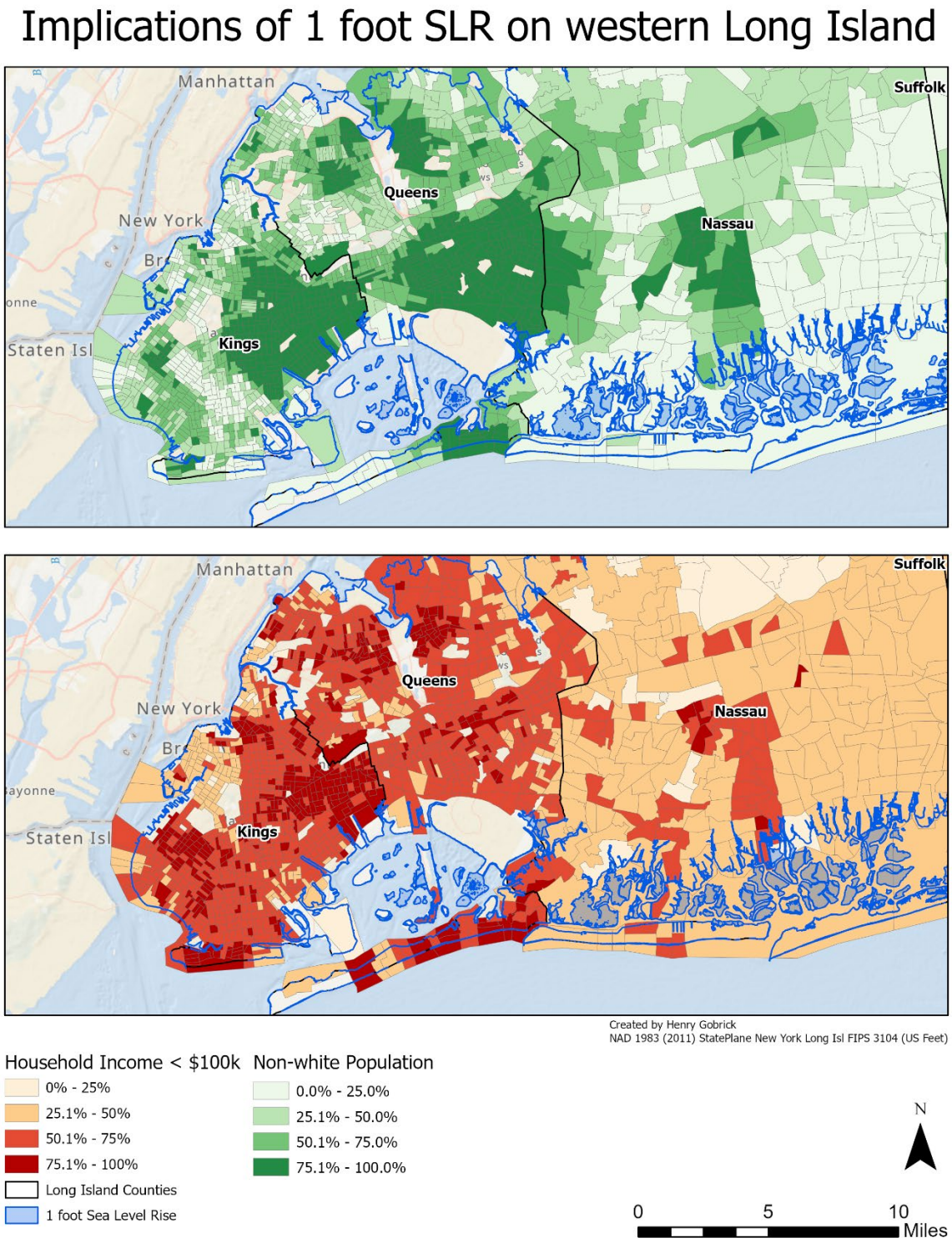

Figure 3-6. Implications of 1-foot SLR on western Long Island

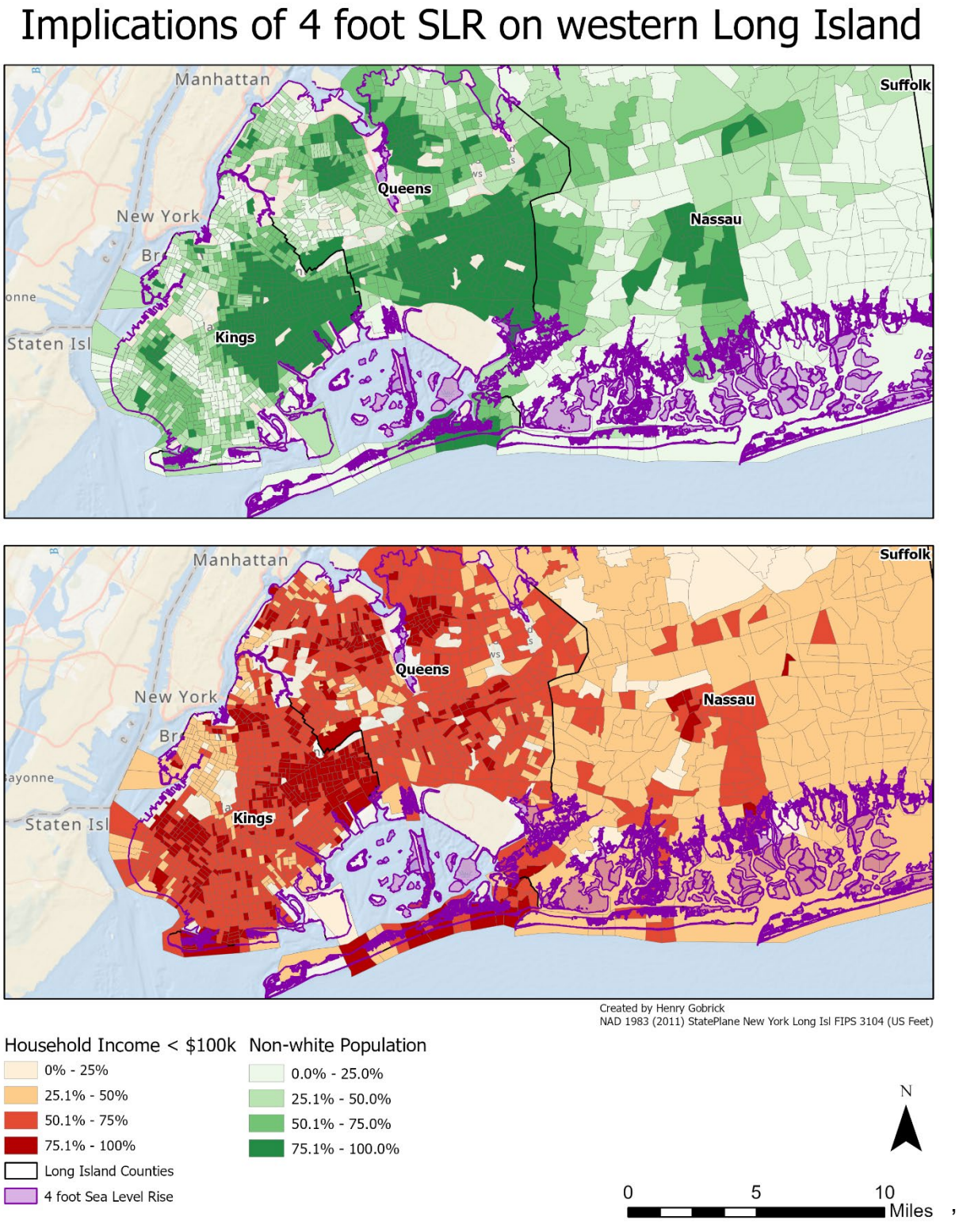

Figure 3-7. Implications of 4-foot SLR on western Long Island

The non-white population, besides in Kings and Queens counties, appears to live mostly inland, away from the majority of the areas that are projected to be inundated. It appears that it is primarily the white population that will face severe inundation in Suffolk and Nassau counties. In Kings and Queens counties, there isn't exactly a minority. In other words, white is the minority for the far western side of Long Island. Fortunately, it does not appear that minority populations will struggle too much with sea level rise. Nearly the entirety of the north and south shores, along with the barrier islands and peninsulas, are predominantly white. While it does appear that Kings and Queens counties will struggle somewhat, particularly in the event of a four foot sea level rise, it appears that those struggling with income will not be affected too harshly. Similarly, it is evident that the non-white population that resides on Long Island will not face much in the way of extreme inundation, relatively speaking. Inundation due to sea level rise, particularly at the 4 foot level projected for 2100 on Long Island, seems to primarily impact those of higher income and the white population.

CHAPTER 4
CONCLUSION

The intention of this project was to analyze the ramifications of inundation due to sea level rise on Long Island. This analysis was done on the island as a whole, but also done on a demographic level. Once dissected on a demographic level, certain areas of Long Island became more of a focus. This was done because of research that suggests that not all demographics are equally able to persevere in the event of serious inundation. As a result, it was found that low income areas on Long Island are not particularly in danger of serious inundation by 2100. This is primarily due to the fact that those low income areas tend to be further inland. On Long Island, the wealthier residents tend to live closer to the shorelines. Similarly, the non-white population on Long Island seems to be in the least danger of serious inundation. Unfortunately, the island as a whole (including its barrier islands) appears to be in danger. In the event of a 1 foot sea level rise, 4% of Long Island will be inundated. For a 4 foot sea level rise, 7.5% of Long Island will be inundated. Both these levels were seen to be realistic SLR projections for the 21st century, with 4 feet being the absolute maximum.

Every piece of data analysis and visualization in this project was done using various combinations of geoprocessing tools and mapping techniques. Utilizing GIS in this way is relatively new and will continue to grow in the future. GIS will continue to support urban planning and will aid in the wake of natural disasters for the foreseeable future. This is especially true if climate change continues to worsen. The results, findings and figures discussed in this project make it clear that Long Island is in great danger of extreme inundation if efforts are not made towards “reversing” climate change. The fight against climate change is certainly on, but a lot more needs to be

done. Ways to help mitigate climate change include recycling, taking public transportation, and swapping our everyday energy sources for “greener” resources, like solar or wind energy.

Pre-existing research on this topic certainly exists for other study areas in the United States. A study done in 2021 discusses minority populations in the coastal Carolina area that are already seeing the “significant threats” of sea level rise (Handwerger et al. 2021). Areas with a high percentage of minority population in the Carolinas are facing extreme flooding, making their lives difficult and forcing many to relocate. This study also notes the fact that communities of color typically do not have the “financial means” to either relocate or rebuild their flooded home. As discussed thoroughly in this project, the Carolinas study also claims that sea level rise acts as a “risk amplifier” for health disparities and existing poor economic conditions.

With pre-existing studies in mind, there are a trilogy of things that I would do differently if I were to do this project again. Firstly, I would analyze the effect of SLR on Long Island and then compare it to other areas in the United States in similar conditions. I would see how the same amount of sea level rise would affect areas that are similar to Long Island and dissect why Long Island may be more (or even less) in danger than those areas. This may be an important factor to aid in the delegation of resources for preparation and/or anticipation. A second aspect that I would do differently is going even further into the future with my research. The sea level rise values chosen in this project were for minimum and maximum projections by 2100. If I was to do this again, I would see how high the sea level would have to rise to inundate around 25% of Long Island, rather than just the maximum 7.5% by 2100. With this level, I could project

just how long it is until Long Island sees various amounts of its surface area completely inundated. The third and final thing that I would do differently if I were to do this project again is to research if any actions are being taken by policymakers specifically in New York State to try and help “reverse” climate change. Obviously, on a national and global level there is great awareness about global warming and changes are slowly being made to try to mitigate it (e.g., electric vehicles) but it would be worth looking into if New York State has made any specific actions or if they are aware of the danger that it would bring to New York in particular. While they could be viewed as simple oversights, these three changes make for excellent “next steps” and open several doors for future research not only for Long Island but for the rest of the world.

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