Mapping Future Population Impacts Caused by Sea Level Rise in Huntington Beach and Newport Beach:
Comparing the Cadastral-based Dasymetric System to Past Dasymetric Mapping Methods

by

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To my Mom, Dad, and Sisters

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AW	Areal Weighting
CEDS	Cadastral-based Expert Dasymetric System
CoSMoS	Coastal Storm Modeling System
DEM	Digital Elevation Model
ENSO	El Niño-Southern Oscillation
FAW	Filtered Areal Weighting
GIS	Geographic Information System
GHG	Greenhouse Gas
GPS	Global Positioning System
GSLR	Global Sea Level Rise
HU	Housing Unit
IPCC	Intergovernmental Panel on Climate Change
MHHW	Mean Higher High Water
NOAA	National Oceanic and Atmospheric Administration
PDO	Pacific Decadal Oscillation
RCP	Representative Concentration Pathways
RSLR	Regional Sea Level Rise
SCAG	Southern California Association of Governments
SLR	Sea Level Rise

Abstract

Due to the intense pollution and warming rates, as well as other strenuous factors, future sea level rise (SLR) is projected to cause severe damage to people that live in coastal areas around the world. The population from Huntington Beach and Newport Beach, California has a high chance of suffering from the imminent impact of SLR. These two cities are particularly appropriate to a study of SLR impacts because they have low-and high-laying lands. Highly developed coast line infrastructure with high property values, and large numbers of people living near the beach.

This study estimates population that may be directly affected by SLR in the two cities by using three dasymetric mapping methods and two SLR projections. The methods are centroid-containment, Filtered Areal Weighting (FAW), and the Cadastral-based Expert Dasymetric System (CEDS). The SLR projections are based on a global and local scale from the National Oceanic and Atmospheric Administration's SLR Viewer. Geographical information systems (GIS) is utilized to digitize, analyze, and compare the most recent spatial data. The project's first objective evaluates SLR effects on populations and neighborhoods in the two cities. Secondly, this project describes and compares results between the three dasymetric mapping methods. Lastly, the mapping results of Huntington Beach are compared to its neighboring and contrasting city, Newport Beach, for further understanding of the mapping results. This study concludes that SLR may impact the wealthy population the most in both cities. Furthermore, this research provides a method for the two cities and other coastal cities in order for them to help people that may be impacted by SLR quickly and more efficiently. Emergency response agencies can also use this research to accurately portray impacts to people caused by pollution, or natural disasters.

Chapter 1 Introduction

Global warming is one of the world's greatest threats, with sea level rise (SLR) being a major factor. The National Oceanic and Atmospheric Association (NOAA) projects that the population will be impacted the most from SLR. This project's main focus is to spatially analyze the population impacts in Huntington Beach and Newport Beach, California, from global and regional SLR projections. In order to portray these impacts, several questions need to be asked. First, what are the impacts to the population at each SLR projection, and in each city? Also, where are the most vulnerable areas impacted by SLR? To solve these questions, this project utilizes the Cadastral-based Expert Dasymetric System (CEDS) created in 2007, originated by Maantay, Maroko, and Herrmann (2007).

Showing where people are impacted by SLR accurately is important so the government knows where to help people more efficiently. With the use of geographical information systems (GIS), this project utilizes necessary census, land use, and assessor data to conduct dasymetric mapping. This project uses CEDS to accurately locate the impacted population from SLR, across Huntington Beach and Newport Beach. A comparison of the past methods, such as the centroid-containment and the Filtered Areal Weighting (FAW), are constructed to portray how the CEDS mapping method is the most accurate when analyzing population effects.

Chapter 1 provides a brief background for this study, by portraying how important SLR is to study and how SLR may impact coastal populations. The first section examines how geographical information systems are important when studying the impacts of SLR. The next section explains how global and regional SLR occurs. Next, a background of the factors and scenarios when projecting SLR is provided. Lastly, the study area section describes the geography of Huntington Beach and Newport Beach.

1.1. Sea Level Rise and GIS

When examining potential environmental impacts, such as SLR, GIS is a powerful science that uses different geospatial tools to visually and statistically explain, describe, and predict patterns across geographical scales. Analyzing the impacts caused by SLR is one of the most important aspects to study in the world today because GIS provides effective monitoring of the environment. GIS also provides an improved understanding of environmental impacts by studying geospatial data across many different scales. To acquire valuable information and data, geospatial technologies, like remote sensing tools and GIS, can be utilized. There are other ways to analyze the societal effects, but GIS has been proven over the years of studies to be the most useful tool in analyzing the societal impacts of SLR around the world (Paul 2018). This section describes how GIS is necessary to study the societal threats and impacts caused by SLR.

GIS can analyze the impacts of SLR in several ways. The most effective way GIS can be used is through environmental data analysis and planning. For example, when studying SLR societal impacts on a regional scale over time, GIS can be used to display and analyze aerial photography and spatial data at different scales. As Paul (2018) mentions, when analyzing spatial data, GIS methods allows for better viewing and understanding of physical features and the relationships that influence in a given critical environmental condition. GIS can also create comparative views of highly susceptible areas, in order to provide safeguards to those areas. For government use, GIS can also be used for disaster management.

In the case of SLR, governments can use GIS to create disaster management maps to help solve and visualize many problems. For instance, a disaster map can show how a region might be affected the most. Then GIS can help by analyzing those regions to mitigate the SLR risks to society to a great extent (Paul 2018). If the government is trying to prepare for SLR risks, GIS is able to predict who and what might be impacted the most over space and time. Also, GIS is able to provide emergency systems a more accurate and faster response to these areas. With that being said, Paul (2018) writes: “GIS enables response teams to gain situational awareness, engage with the public, and understand the impact in any environmental event” (Paul 2018, 1).

1.2. Contributions of Sea Level Rise

As a by-product of the Industrial Revolution, which has been one of the main causes of increased fossil fuels emitted into the atmosphere, sea level rise has been increasing around the world at an alarming rate. The Intergovernmental Panel on Climate Change (IPCC) (2014), the leading group in studying SLR, found that the global sea level has risen at an average rate of 1.8 millimeters per year (mm/yr), with a range of 1.3 to 2.3 mm/yr, since 1961, and since 1993 at 3.1, with mm/yr a range of 2.4 to 3.8, mm/yr. Global SLR has been driven in part by the accumulation of greenhouse gases in the atmosphere, which traps heat and raises global temperatures. The primary causes of SLR are thermal expansion of ocean water, which is the expansion of ocean water as it warms, and the melting of glaciers and ice caps from Greenland, Antarctica, and even Alaska. The other causes include wind patterns, surface air pressure, the movement of the land itself, and extreme events like storms and earthquakes.

The global drivers of SLR go hand in hand with the regional drivers, but not the other way around. The global sea level rise (GSLR) takes the average of the melting of ice sheets and glaciers, groundwater expansion and steric expansion. These determinants play a part in the regional sea level rise (RSLR) factors. For instance, erosion is caused by the expansion of water, so when the water warms, the water level increases, making the land erode. Also, when glaciers melt, the water melts into rivers, causing more water to runoff into the ocean.

In this SLR process, ocean circulation is caused by currents and affects the RSLR because different types of currents occur in different places in the world. The ocean-atmosphere interaction is the process of wind and the temperature affecting the ocean. This affects the RSLR because wind and weather systems are different around the world. Next, the terrestrial water storage is the process of taking water from the ocean and storing it on land, like a dam. Groundwater withdrawal is regional and happens when the water from the land area releases water into the ocean.

Climate change is the most important factor to look at when studying SLR because it causes most of the other factors of SLR to occur. Experts have found that temperature increases are mostly due to the increase of emitted greenhouse gases (GHG) (IPCC 2019). GHGs are human made, or natural, pollutants, that cause the atmosphere to increase in temperature. Then, the atmosphere warms the land and the ocean, causing the water level to rise. The higher rate of GHGs emitted results in the atmosphere increased at a higher rate, causing the ocean to warm more and increasing the level. The temperature increase is widespread over the globe, but is greater at higher northern latitudes and developing countries because they pollute more GHGs at a higher rate than developed ones.

Understanding the different GHGs and how they are made is very important because an excess of GHGs into the atmosphere is a primary determinant in Earth's climate change. These emissions include carbon dioxide, which is the most prominent and dangerous emission, and also gasses like methane and nitrous oxide. Carbon dioxide is caused by fossil fuels, from energy sources of oil, coal, and natural gas. Deforestation, and decay of biomass also create a large amount of carbon dioxide. Increases of methane are caused by agriculture and fossil fuel use. Furthermore, nitrous oxide is caused primarily by non-environmental agriculture practices.

Melting of glaciers and ice sheets is one of the most important factors of SLR because it adds the highest volume of water to the ocean, due to the warming caused by pollution. There are two ways land ice affects the sea level. First, the large glaciers and ice sheets generate a gravitational pull that draws ocean water closer, raising sea level near the ice masses. As the ice melts from Greenland, Antarctica, and Alaska, the amount of ice mass on land declines, decreasing its gravitational pull on the ocean water. Additionally, the loss of ice mass results in uplift of the land mass under the ice (Committee 2012). These two effects, combined, cause the local gravitational attraction to decrease, as the land ice mass decreases. As the land in the vicinity of the ice rises, it causes the sea level to fall. However, the sea level increases everywhere else. Second, when the ice melts, it causes the SLR through its gravitational and deformational effects. Since the distribution of the ice melting is not uniform over the globe, the SLR varies among regions. This figure shows how each body of melting ice and glaciers affects the different regions. The sea level falls near the shrinking ice mass and rises everywhere else. The combined effect, caused by water mass entering the ocean and altered gravitational attraction, results in a spatial pattern of sea level rise that is unique for each ice sheet or glacier.

While the melting of glaciers and ice sheets are significant determinants in SLR, the effects of the hydrological cycles also play a part in RSLR. Hydrological cycles are created, and changed by ocean surface heating, surface air pressure, and wind patterns. In this project's study areas, three hydrological cycles take place along the west coast of the US. These hydrological patterns affect winds and ocean circulation. The smaller hydrological cycle is the Pacific Decadal Oscillation (PDO), and this occurs every decade. The other cycle El Niño-Southern Oscillation (ENSO), has two phases. ENSO is seasonal and occurs every two to seven years, and has a higher effect in the Northern Hemisphere during the winter months. During the warm phases, El

Niño raises the local sea level. El Niño creates low atmospheric pressures and west-southwest winds that elevate sea levels on the west coast. The other phase is known as La Niña, and this has a smaller effect on the SLR. La Niña occurs during cold seasons and decreases local sea level during this time. Additionally, ENSO may also play a significant role in decadal and longer sea level variability than PDO.

Another aspect of SLR is the movement of land caused by geological processes and anthropogenic activities. Land movement is very subtle and happens over a long time period. Geologic processes include glacial isostatic adjustments, explained in the melting of ice sheets and glaciers, tectonics, and compaction of sediments. Tectonics are land motions caused by strain buildup along faults and release during an earthquake, which are extreme events and can cause a major increase in SLR. On the US west coast, the two tectonic regions that exist are the Cascadia Subduction Zone and the San Andreas Fault Zone. This project's areas of study are located in the San Andreas Fault Zone. This tectonic region's plates are sliding past one another south of Cape Mendocino, California, all the way just south of Mexico. This fault zone is made up of multiple sub-parallel faults, each with limited extent and unique seismotectonic character. Compaction of sediments also occurs in this process. The compaction may rearrange the mineral matrix of sediment, reducing its volume. Sediments are matter that settles to the bottom of the ocean, like rocks and sand. The amount of compaction depends on several factors. These factors include the mechanical and chemical properties of the sediments, the content of the water, and the loading history of the sediments. The anthropogenic activities include groundwater, or oil extraction, which can lower large areas of the land surface. SLR impacts low areas, so if they decrease in height, then those areas become more susceptible to being impacted by SLR.

1.3. Study Area

Huntington Beach is located on the Orange County coast, as shown in Figure 1, with a population of 198,724 people in 2018. Within its 31.88 square miles, Huntington Beach is known for its abundance of beaches, the sunny and warm Mediterranean climate, and its casual lifestyle. The city provides different resources that help better the community, scenic views, diverse neighborhoods, open spaces, all kinds of services, and a lot of shopping that creates a unique sense of place and quality of life. This sense of place has enticed over fourteen million people a year to visit, which is the most in all of Orange County.

Additionally, Huntington Beach benefits from higher median household incomes and median home values as compared with the State. Provided by the US Census Bureau for Huntington Beach, the city has the fourth largest population in Orange County. Huntington Beach was the twenty-second largest city in California by the total population in 2018. Also, Huntington Beach has a median household income of $88,079 with the tenth highest median property value in the county, at $688,700 (US Census Bureau 2018a).

The city's business community is exceptionally diversified with no single industry or business dominating the local economy. Local companies include high technology, petroleum, manufacturing, computer hardware and software, financial and business services, hotel and tourism, automobile services, large-scale retailers and surf apparel, just to name a few. Huntington Beach has relied on oil for its income since the 1920s, but the oil is becoming depleted, so Huntington Beach is turning to the hotel and tourism industry as its primary revenue source.

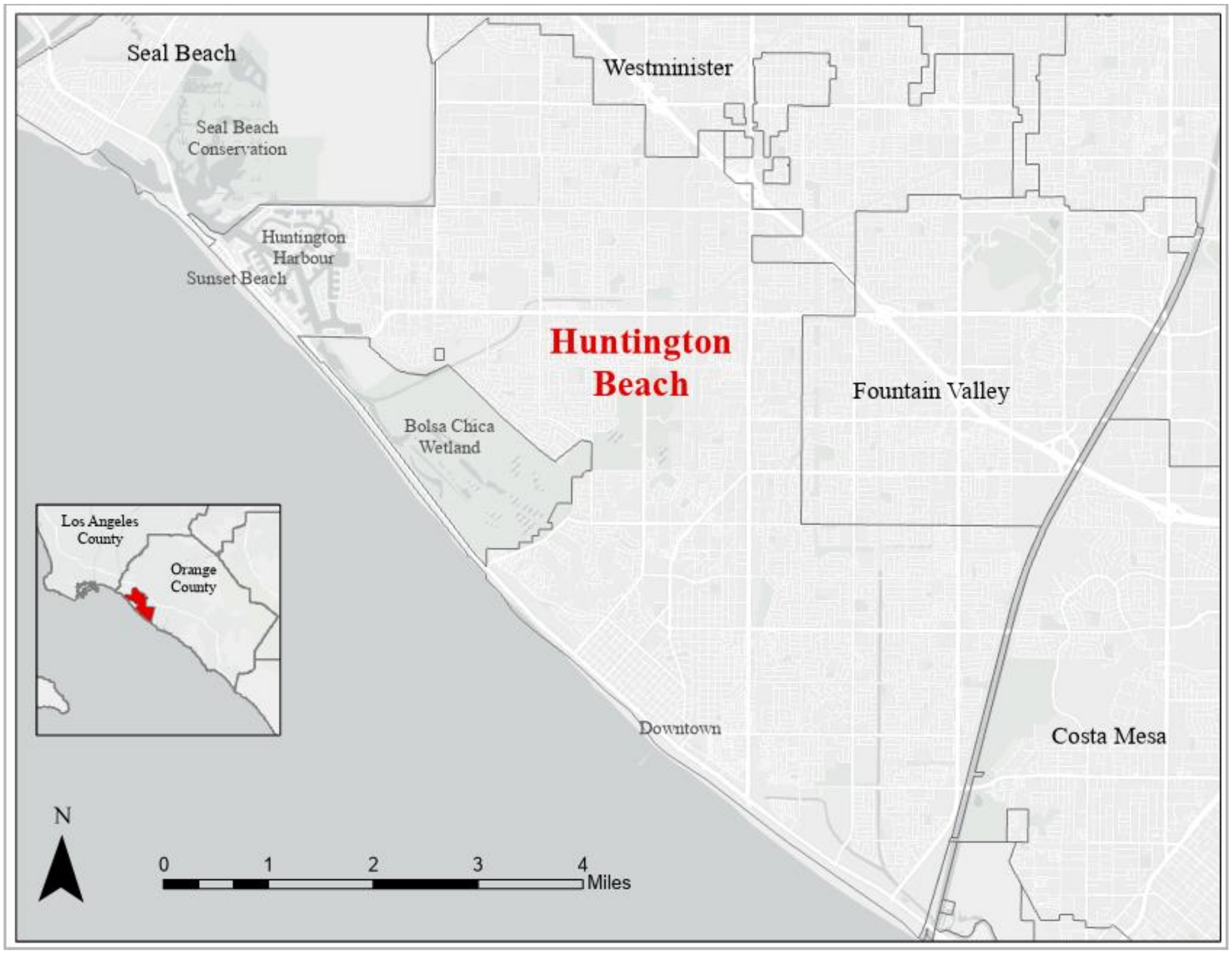

Figure 1: City of Huntington Beach, California

Newport Beach, California, is compared to Huntington Beach in this study. As shown in Figure 2, Newport Beach is located in Orange County, just south of Huntington Beach, with a population of 86,813 people in 2018. The population isn't very diverse, containing mostly a white population. Within its 52.98 square miles, Newport Beach is known for its demographic composition, economically and socially successful residents. Newport Beach is similar to Huntington Beach in that the city provides different resources, scenic views, open spaces, all kinds of services, and a lot of beautiful shopping areas that create a lavish lifestyle. However, Newport Beach has more expensive homes and has a population that is eighty percent white.

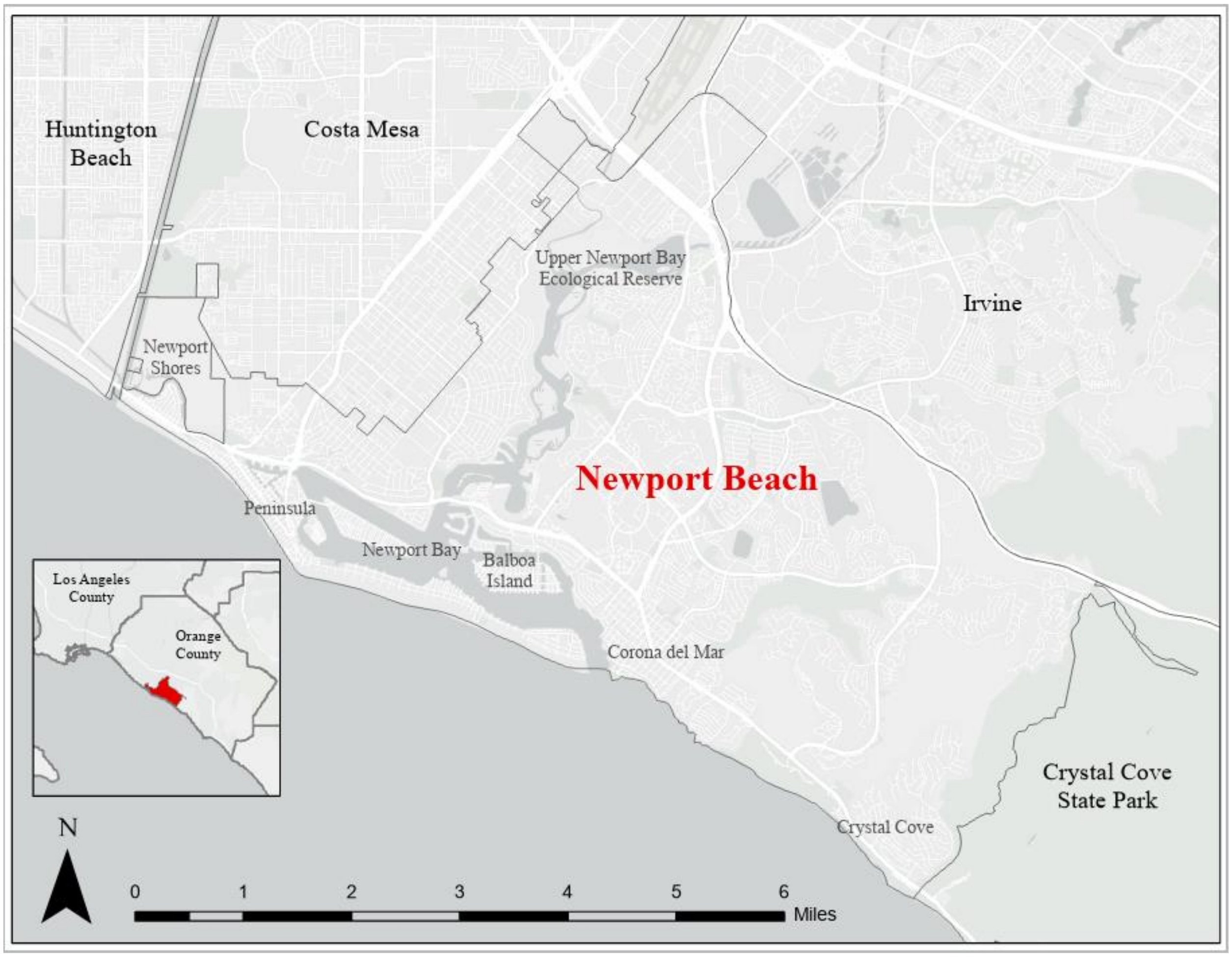

Figure 2: City of Newport Beach, California

This city benefits from some of the highest median household incomes and median property values as compared with the state and the county. The city has the thirty-second largest population in Orange County, and is outside the top fifty 2018 most populated cities in California because the population size is so small (US Census Bureau 2018b). Even though Newport Beach contains a small number of people, the city has the seventh-highest median household income in the United States at $119,379, along with the highest median property value in Orange County at $2,119,700 (US Census Bureau 2018b).

Since this study analyzes the population impacts of both Huntington Beach and Newport Beach, it is important to examine the cities' residential areas. Table 1 represents Southern

California Association of Governments' (SCAG) 2018 number of housing units in both cities, which are provided in their 2019 local profiles of the City of Huntington Beach and Newport Beach. From this table, the percentage of total units in both cities is about the same for each housing type. However, the total number of housing units in Huntington Beach is almost double that of Newport's. Additionally, the population that lives in the Huntington Beach housing units is more than double than that of Newport. This information is important to understand because the data that is used in this study helps create the mapping methods and estimate the population impacts in both cities.

Table 1: 2018 Housing Units in Huntington Beach and Newport Beach

City	Housing Type	Number of Units	Percent of Total Units
Huntington Beach	Single Family Detached	39,126	47.9 %
	Single Family Attached	9,464	11.6 %
	Multi-family: 2 to 4 units	9,665	11.8 %
	Multi-family: 5 units plus	20,314	24.9 %
	Mobile Home	3,087	3.8 %
	Total	81,656	100.0 %
Newport Beach	Single Family Detached	20,141	45.1 %
	Single Family Attached	7,010	15.7 %
	Multi-family: 2 to 4 units	5,063	11.3 %
	Multi-family: 5 units plus	11,336	25.4 %
	Mobile Home	1,120	2.5 %
	Total	44,670	100.0 %

Source: Nagel (2019) and Semeta (2019)

The following chapters provide information on how this project estimated the population affected by SLR and how these results were compared by projections, years, and cities. Chapter

2 analyzes the past work that was done about analyzing SLR. This chapter also looks into how this project will be created, by following these past works. Chapter 3 provides information on the methods this project undertook to map SLR and analyze its impending impacts on Huntington Beach and Newport Beach.

Chapter 2 Literature Review

Sea level rise has been studied extensively over the last half-decade, and yet very little is being done to protect coastal areas, even in the most developed countries. A multitude of factors affect SLR, which include land movement, ocean sand removal, earthquakes, and storms. However, the IPCC states that climate change is the major cause of SLR. Because Earth is warming, due to increased human actions, the ice caps in the Northern Hemisphere have been melting at a much faster pace over the last decade than at any time since the Industrial Revolution. Also, climate change warms the ocean water, making the water denser. These two effects, from climate change, have caused the sea level to rise at a much faster rate over the last decade. The projected impacts of SLR will have effects on the coastal environments, the population in or near coastal areas, and the economy.

Since this study analyzes the impacts to population from SLR projections up to 2100, it is necessary to show all of the possible SLR estimations. To do this, this project first explains how the global and regional SLR projections are different by examining two scientific reports. These projections are used in this study to show the purpose of providing each SLR projection. Then this project describes the future physical impacts of SLR in coastal areas. The description of the physical impacts supports the reasoning behind this project's importance of analyzing population impacts of SLR. Lastly, past mapping methods are examined to show the population impacts of SLR. Some of these mapping techniques were used to examine how SLR may impact the population of Huntington Beach and Newport Beach over time and space. By mapping population impacts in Huntington Beach and Newport Beach, the goal is to inform policy makers in local and federal government how they might best invest in more coastal management projects to prevent a catastrophe in the future.

2.1. Projections of Sea Level Rise

When projecting for future SLR, it is important to account for all of the possibilities that may happen. To do this, this section analyzes the SLR projections at the global and regional scale because predictions are different at each scale. For instance, GSLR is projected by estimating the low, medium, high, and extreme GHG emission levels at different ranges of years for the world. However, when projecting for RSLR at different years, estimated ranges of all the causes of SLR are all taken into account in specific areas. The causes of SLR, when estimating for RSLR, include the projections of steric expansion, land expansion, wind, hydrological cycles, currents, and the melting of glaciers and ice caps. Also, RSLR projections use historical data of SLR accumulated at tide gauges. These tide gauges are located in numerous coastal areas.

By providing both the GSLR and RSLR projections, this project accounts for all of the possible SLR estimations. It is important to describe the different types of SLR projections provided by the IPCC (2019) and the Committee on Sea Level Rise in California, Oregon, and Washington (2012), even though this project gathers the SLR data from NOAA. The SLR data provided by NOAA closely resembles each of the reports' projections. As described in section 2.1.1, the 2019 IPCC report on climate change (IPCC 2019) is used to explain how to estimate for GSLR and its determinant factors correctly. Then, in section 2.1.2, the Committee on Sea Level Rise in California, Oregon, and Washington (2012) describes how RSLR is different than GSLR. This section also provides the Committee's (2012) projections and how they found the RSLR projections. Lastly, in section 2.1.3, Newport Beach's projections are provided to show how different cities calculate for SLR in their city.

2.1.1. Global Sea Level Rise Projections

The IPCC examined projections of SLR in order to figure out how much sea level may rise per year on a global scale. The IPCC is the leading group of projecting climate change and everything that is caused by it, like SLR. The IPCC's studies, based on 2014 estimates, have found the GSLR by taking into account the different pollution levels, warming of the oceans, and the melting of ice glaciers. For each one of these aspects, the IPCC (2019) created models for each pollution level and found how much the global sea level would rise with each consideration. The IPCC (2019) made these different scenarios because pollution levels may decrease or increase in the future, making SLR projections not always exact.

While GHG scenarios determine the GSLR projections, the current pollution levels are at a high level. These high levels of GHGs make the Earth's atmosphere warm faster, causing the ocean to warm, making the ocean denser. As a result, the sea level rises at a higher rate. The IPCC (2019) has taken these projections to estimate GSLR until 2100. Although, after 2050, it is especially harder to project because there can be different levels of pollution emissions in the future. Because of these inaccuracies, the IPCC provides four GSLR projections that include low, medium, high, and extreme levels. The IPCC does this because pollution could either decrease to lower levels of pollution, due to the abundance of clean energy projects or the creation of stricter pollution laws, which would make SLR rates decrease. However, pollution could also increase to even higher levels, due to the amount of money there is in the energy industry. For instance, billions of dollars are still being spent by the United States alone on long-term fossil fuel energy infrastructure. In this case, higher levels of pollution levels would increase SLR levels.

This project examines the GSLR likelihoods, derived by the IPCC's (2019) conclusions of its pollution models. As shown in Table 2, the GSLR projections are based on the low to high scenarios of the amount of Representative Concentration Pathways (RCP) of GHGs emitted into the atmosphere. RCP2.6 is the lowest concentration, RCP4.5 is the medium concentration, and RCP8.5 is the highest concentration of GHGs. The IPCC (2014) made these projections from the data that they collected, from 1986 to 2005. Furthermore, they made corrections in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019). Each GSLR projection scenario is shown in Table 2, and is based on the levels of GHG concentration that are most likely to happen at the different ranges of years. The ranges in parenthesis reflect the possible ranges of SLR in meters and the numbers outside reflect the ranges' means. This project uses the SLR scenarios at RCP8.5 in 2050 and 2100 as reference when gathering the spatial data from NOAA's SLR viewer.

Table 2: 2015 Global Sea Level Rise Projections for Each Concentration Scenario

Year Ranges of Global Mean SLR	RCP2.6	RCP4.5	RCP8.5
2031-2050	0.17 (0.12–0.22)	0.18 (0.13–0.23)	0.20 (0.15–0.26)
2046–2065	0.24 (0.17–0.32)	0.26 (0.19–0.34)	0.32 (0.23–0.40)
2081–2100	0.39 (0.26–0.53)	0.49 (0.34–0.64)	0.71 (0.51–0.92)
2100	0.43 (0.29–0.59)	0.55 (0.39–0.72)	0.84 (0.61–1.10)

Source: IPCC (2019)

2.1.2. Regional Sea Level Rise Projections

While the IPCC is the leading group in climate change, more accurate projections of SLR exist, especially when dealing with specific places. This project requires SLR projections at a more regional level, as well as a global scale. Even though more uncertainties in projecting SLR exist at a more regional level, the Committee (2012) gathered the regional projections for just the west coast of the United States. In order to make a regional model, this Committee used some of the same methods of projection, as the IPCC (2007) did to find GSLR. The Committee (2012) also accounted for the recent data on major changes of ice sheets and glaciers as melting occurs.

They also used more recent historical SLR levels from all of the local tide gauges on the west coast. The Committee (2012) found that the expected SLR in Los Angeles may be 4.6–30 cm. for 2030, 12.7–60.8 cm. for 2050, and 44.2–166.5 cm. for 2100, relative to 2000. From these projections, this project will use the 2050 and 2100 projections at the highest projection.

The Committee (2012) included factors that pertain to this project. These factors are the effects of: land elevation in California, El Nino, and the motion of the North American Plate. The El Nino Southern Oscillation affects sea level on seasonal, especially winter months, and decadal and longer timescales. All of the SLR factors projections and their sum are estimated by the Committee (2012). The most important projection and sum are Los Angeles because they are used in this study to estimate the RSLR in Huntington Beach and Newport Beach. Through the use of global and regional projections from the IPCC (2019) and the Committee (2012), this project requires making models from both scientific approaches to take into account all scenarios of SLR.

The Committee examined the IPCC's GLSR estimations from 2007 and discovered that there was a bias in some of the ocean temperature measurements in the IPCC's 2007 report. The Committee's (2012) report added the ice melting aspect, which the IPCC didn't. The Committee's (2012) report also found that the bias gave warmer temperatures in the IPCC's 2007 report than the true values. Data sets that were corrected by the Committee found that thermal expansion for the 1993 to 2003 period was significantly lower than what the IPCC, in 2007, originally found. Also, by contributing ice loss from Greenland, Alaska, and Antarctica, the Committee found that the GSLR is currently increasing. However, major uncertainties exist when projecting the ice loss.

2.1.3. Newport Beach Sea Level Rise Projections

The City of Newport Beach has done extensive GIS research and analysis for projecting their city's SLR and the impacts up to 2100 (Moffatt & Nichol 2019). The city's Information Systems department used the California Coastal Commission mapping tool, Our Coast, Our Future, and used the data called Coastal Storm Modeling System (CoSMoS) SLR data from the USGS. The tool and data enabled Newport Beach to get a better projection than the NOAA SLR data, available at 25 cm increments. For 2030, 2050, and 2100, they were able to collect SLR data that was close to the actual projections, as shown in Table 3. Also shown in Table 3, the city's projections were based on the Ocean Protection Council report in 2018, which is the most recent and accurate projections for Newport Beach. In the CoSMoS SLR column are the datasets that the city used from USGS to project the SLR inundations at the intermediate to high possibility scenario of the amount of pollution in the city. The sixty-seven percent probability is the low amount of pollution projected, and the most conservative projection. The five percent column, in the middle, is the medium pollution projection. The other five percent column is the high pollution projection. Lastly, the H++ scenario is the extremely high projection of pollution. Newport Beach obtained these four ranges from the IPCC (2014). However, the project uses the updated projections from the IPCC (2019) and the Committee (2012) and gathers the SLR data from NOAA's SLR viewer for both Huntington Beach and Newport Beach. This project uses the NOAA mean higher-high water (MHHW) datasets, from one to six-feet by rounding the projections up, so there can be a better distinction of the vulnerable places.

Table 3: Newport Beach SLR Projection

Year	CoSMoS SLR Scenario Selected	67 % Probability SLR Scenario	% Probability SLR Scenario	% Probability SLR Scenario	H++ Scenario
2030	0.8 ft.	0.5 ft.	0.6 ft.	0.7 ft.	1.0 ft.
2050	1.6 ft.	1.0 ft.	0.6 ft.	0.7 ft.	1.0 ft.
2100	4.9 ft.	3.2 ft.	4.1 ft.	6.7 ft.	9.9 ft.

Source: Moffatt & Nichol (2019)

2.2. Alternative Ways to Analyze Future Impacts of Sea Level Rise

Most of America's largest and economically important cities are located near the coast, and if nothing is done about SLR, then the US will suffer greatly. America's coasts are important to the country's societal and economic well-being. As described by NOAA (2020), forty percent of the population reside on America's coasts, which consists of ten percent of America's land mass. Additionally, the economic value of the coastline generates 8.6 trillion dollars in goods and services. Furthermore, America's coast employs 56.8 million people, which generates 3.5 trillion dollars in wages annually (NOAA 2020). If nothing is done to minimize future SLR, a lot of people, as well as infrastructure, will be impacted. To prevent these impacts from rising sea levels, the government needs to invest in coastal management projects, such as sea walls, to help diminish the inevitable SLR impacts. This section examines how different articles use SLR to show the impacts in the future using GIS.

2.2.1. Economic Impacts of Sea Level Rise

Analyzing population impacts is very important to protect citizens, economic impacts affect people, cities, states, and the country as a whole. Development, like restaurants, retail stores, hotels, and homes, would be impacted by SLR. SLR causes the beach length and width to decrease exponentially, which makes housing prices decrease. Decreasing the length of the beach can potentially entice less people to visit the beach because there would be less space between people. Another by-product of beach regression is that tourism would be affected in cities that count on coastal tourism the most. The affected coastal tourist industry, such as restaurants, retail stores, hotels that rely on the beach, and events on the beach, would lose an extraordinary amount of money because fewer people wouldn't visit the beach. For instance, Boeing and Huntington Beach's extensive oil fields were once the drivers of city's economy by providing jobs and money to the government. However, now that Boeing is gone and Huntington Beach's oil fields have been depleted, the city will have to rely heavily on their coastal development for tourism sooner than they hoped. Huntington Beach will also have to rely on their housing's high property taxes. Just like Huntington Beach, most coastal cities in the US rely heavily on their tourist industry and high property taxes.

To analyze the impacted housing in coastal areas, different types of economic information and spatial data are required to gauge how each development type is affected due to SLR. In the Felsenstein (2013) article, social and economic vulnerability of coastal communities of the two most populated metropolitan areas in Israel, Haifa and Tel Aviv, are analyzed through the use of GIS. The vulnerability of coastal communities is assessed through the use of Moran's I statistics, which are spatial correlation coefficients. Elevation, gradient, and the disabilities data are spatially correlated to the housing prices as the economic vulnerability, and income, age groups, and the number of vehicles per household as the social indicators. It is essential that this project used housing information, but it did not use housing prices. Particularly, this project will only use the number of housing units. Felsenstein (2013) also used the social and economic vulnerability were also made into a three-dimensional (3D) model, based on the different vulnerabilities at a two-meter SLR inundation. The author also provided a community vulnerability aspect in their research. Some of the socioeconomic data that this article included was the occupation, education, ethnicity, age and marital status at the tract level. When using GIS, the analysis was made into a 3D model and showed where the impacts were based on that. This project did not create a 3D model or analyze data the tract level, however, it developed a two-dimensional model analyzing population impacts at the block group and parcel levels.

While Huntington Beach is projected to be one of the most vulnerable cities in Orange County, due to SLR, North Carolina is projected to have one of the most vulnerable coastlines in the US. In Bin, Poulter, Dumas, and Whitehead's (2011) article, GIS was used to measure the impact of SLR on North Carolina's four counties, New Hanover, Dare, Carteret, and Bertie, coastal real estate. The authors created several different inundations to study, which they acquired from the IPCC in 2007. The inundations included: "11 centimeters (cm) increase in sea level by 2030 (2030-Low), a 16-cm increase by 2030 (2030-Mid), a 21-cm increase by 2030 (2030-High), a 26-cm increase by 2080 (2080-Low), a 46-cm increase by 2080 (2080-Mid), and an 81-cm increase by 2080 (2080-High)" (Bin 2011, 756). The data that he used to study the real estate impacts were property parcels and centroid points for each parcel. These centroids portray the geometric center of a polygon, not just the approximate middle. The geometric center of a polygon takes into account the vertices' locations and angles between edges. The centroids were also used to show the elevation of the parcels. It is essential for this project to include the centroids so it can provide the elevation of parcels because it is a huge factor in analyzing SLR. Bin, Poulter, Dumas, and Whitehead's (2011) process provides valuable information on how to show the impacts of the housing units within different SLR projections. This project analyzed land use parcels and the assessor data attributes, which included the number of housing units in each parcel, to estimate population impacts by future SLR.

2.2.2. Environmental Impacts of Sea Level Rise

Coastal wetlands have a real chance of having major impacts cause by SLR. Huntington Beach and Newport Beach have large conservation areas with an enormous amount of wildlife in them. The wetlands are in low lying areas, which makes them extremely vulnerable to SLR. Schmid, Hadley, and Waters (2014) provided a SLR study of Charleston, South Carolina that shows how to convey the necessary data to fix accuracy limitations and uncertainties that come along with portraying a SLR model. The authors provide a marsh/wetland migration model at a SLR inundation range of 0.3 to 1.8-meters and at 0.3-meter intervals. It also incorporates shallow coastal-flooding extents, which includes the effects of potential SLR scenarios, as discussed earlier. The data Schmid, Hadley, and Waters (2014) used was NOAA's mean higher high-water inundations (MHHW). These SLR inundations, provided by NOAA, are the projections that this project will use. Schmid, Hadley, and Waters's (2014) article is just one example of how SLR may impact the environment in other places. This study also works the MHHW datasets of SLR.

2.2.3. Societal Impacts of Sea Level Rise

When dealing with societal impacts caused by SLR, many different types of people of all ages, and in different socioeconomic classes, need to be considered. A paper from the "California Climate Change Center," by Heberger, Cooley, Herrera, Gleick, and Moore (2009), wrote about how to analyze the population impacts of SLR on the California coast. To analyze the population impacts, the authors overlaid SLR inundations and erosion hazard maps with the year 2009 census block data in eleven California cities to show who might be impacted in the future. They assumed that the population is distributed evenly within a block group's boundary. However, the problem with this method is that it may under or overestimate the actual risk due to the clustering of houses in the block groups. The authors used the environmental justice framework to show potential inequalities in who is likely to be directly impacted to SLR, within the geographic units at which relevant political decisions are made. To do this, they characterized the key demographics and their vulnerability factors based on three phases – pre-disaster, during the disaster, and the recovery and reconstruction phase. These vulnerability factors produced a relationship between the overall human impact of SLR. When analyzing disasters in the UNITED STATES between 1970 and 1980, Herberger et al. (2009) found that the white population had $2,370 less of a financial burden following an environmental disaster than the other racial groups in the California cities. This information is important when analyzing the sociodemographic impacts.

When analyzing societal impacts, Heberger et al., (2009) environmental justice model included all vulnerable demographics. These demographics included children, elderly, homeless, and incarcerated residents. The authors analyzed these societal impacts in such a way because, according to the IPCC in 2007, vulnerability to climate change is the degree to which these demographics are susceptible to, and unable to handle, adverse impacts. They later urged further studies to look into possible inequities at different spatial scales within cities, neighborhoods and metropolitan regions. This project, however, focused on the total population impacts and examined population data at different spatial scales over two different cities.

2.3. Mapping Population

Correctly showing the impacts of the population is important to show where people will need to be helped the most at different SLR inundations. In Maantay and Maroko's (2009) article, "Mapping Urban Risk: Flood Hazards, Race, & Environmental Justice in New York," they used a novel approach, called the Cadastral-based Expert Dasymetric System (CEDS), to show where people would be impacted by 100-year flooding in New York City. The authors also compared CEDS to past dasymetric mapping methods to show the superiority of CEDS when finding impacts to population, from SLR. One of the past mapping methods used was the centroid-containment method, which were explained by Maantay and Maroko (2009) as the least accurate method for locating population impacts. However, in a previous article, "Mapping Population Distribution in the Urban Environment: The Cadastral-based Expert Dasymetric System (CEDS)," Maantay, Maroko, and Herrmann (2007) described the Filtered Areal Weighting (FAW) method as a more accurate method than the areal weighting and the centroid method. The centroid-containment, FAW and CEDS methods will be created in this study.

2.3.1. Centroid-Containment Method

First, the centroid-containment method is a very simple and imprecise mapping technique. This method, as explained by Maantay, Maroko, and Herrmann (2007) and by Maantay and Maroko's (2009), is a common method that uses census centroids, portrayed as a point in the geographic center in either the block group or census tract areas. The centroid method is simple because it only gathers census data if the centroid is within the SLR inundation, and excludes the centroid if it is not within an inundation. Also, this method is inaccurate because, when accounting for the census data, the centroid method may over or under estimate the affected population by SLR. For instance, if centroids are covered by a SLR inundation, the method collects all of the population in that block group even though it may not affect the whole block group or any residential areas. Also, if an SLR inundation does not cover centroids, the method does not provide any of the population in that block group even though it may cover residential areas. This study used this method to compare with the CEDS method.

2.3.2. Filtered Areal Weighting

The next method is the Filtered Areal Weighting (FAW) method, in which Maantay, Maroko, and Herrmann (2007) described in their article as a more accurate method than the Centroid method. The reason the FAW method is more accurate than the centroid method is because the FAW method finds the residential areas within flood zones. The authors created the FAW method by combining residential parcel data, then calculating the amount of residential areas impacted by flood zones in each census block group. Also, this article described how it was less accurate than the CEDS method when mapping for the population in 100-year flood zones in New York City. The FAW method is less accurate than the CEDS because it only accounts for the affected residential area (RA) from the parcels. By accounting for the area only, some of the population numbers might get left out of the total population. To find the total population, Maantay, Maroko, and Herrmann (2007) found the area of affected residential parcels in the flood zones and in each census enumeration area. Then these parcels were divided by the total area of residential parcels in each enumeration area, which provided the percentage of affected residential area. Finally, the percentage of affected residential area in each census area was multiplied by the total population numbers in the census area. This calculation provided the total population affected by the flood zones in the tracts and block groups. The calculation explained here was used in this study, in both Newport Beach and Huntington Beach.

2.3.3. Cadastral-based Expert Dasymetric System

The last method discussed in this chapter is the CEDS method. Maantay and Maroko (2009) described this method as the most accurate mapping method to find the population affected by flood zones. The CEDS involves the process of disaggregating the spatial data to a finer unit of analysis, using additional data to help refine locations of population, or other phenomena being mapped. It is also not bound to using the locations of census tract boundaries, or other administrative zones that have been created arbitrarily. This method is important when estimating for population information because population distribution is much more heterogeneous, which makes the CEDS a more superior choice than the previous two methods. Maantay, Maroko, and Herrmann (2007), and Maantay and Maroko (2009) both used New York City for her analysis because the CEDS works better in areas with high population densities. In this study, the CEDS was used in two cities. One of the cities, Huntington Beach, is largely built up and has a high population density, while Newport Beach is the opposite.

The reason why the CEDS technique is more accurate is that it uses land use parcel data, and the number of residential units (RU) from assessor information in those parcels. By analyzing the number of RUs in the parcels, this data is known as the property tax-lot data. Tax-lot data is used in recording property ownership, valuation, and tax collection. Maantay, Maroko, and Herrmann (2007) used zoning designation, land use, residential units, and lot size, which this project used as well. The CEDS uses the number of RUs as a proxy for population distribution, so the more potential living accommodations the higher the population.

The aggregation of population impacts is explained for each mapping method. The CEDS method is shown by creating a population density map of the number of RU impacted by SLR. Finally, the population data that Maantay, Maroko, and Herrmann (2007) used was total population, non-Hispanic white population, non-Hispanic black population, non-Hispanic Asian population, and Hispanic population and served to populate the choropleth map at the block group level. This project only used the total population and the area data at the block group, and also created choropleth maps.

In order to provide the right population data, this project used the process and data described by Maantay, Maroko, and Herrmann (2007). This article describes how they created the more accurate CEDS, and compared it to the centroid-containment, and FAW method in more detail. To do this, they aggregated the population data from the census tract with the census block groups, and provided calculations to provide a better population representation with the cadastral parcel data. From the cadastral data, or land use parcels, Maantay, Maroko, and Herrmann (2007) used the attributes residential area (RA) and the number of RUs to estimate for population. Then they performed numerous calculations for a better spatial representation and estimation of the population while using the census tracts, block groups, and cadastral parcel data. They also used simple linear regressions for a more comprehensive analysis of the derived populations. As mentioned before, this project followed this method except for the census tract, and compare it to the centroid and FAW methods in order to show the superiority of this novel dasymetric mapping technique.

The calculations that this article explains are very important to understand in order to produce the accuracy and validity of the dasymetrically derived populations. First, Maantay, Maroko, and Herrmann (2007) produced the adjusted residential area (ARA), which was the total building area multiplied by the ratio of the number of residential units and the total number of units. Providing this value, with the addition of residential units, they were able to generate a tax lot-level spatial data layer. Then, several dasymetric derived populations were calculated from the block group and the tract levels. The first was a general equation by multiplying the census population with the ratio of population proxy units, the RA and RU. This calculation resulted in four dasymetrically derived population values for each tax lot, which were “tract ARA, tract RU, block group ARA, and block group RU” (Maantay 2007, 87). This project only calculates for the block group. Then, for the CEDS, tract data were disaggregated down to the parcel level and then re-aggregated up to the block group, which was a necessary starting point. In order to account for differences of the block group and tract level, the absolute value of the different between census populations and estimated populations were calculated. After re-joining this new population difference with the parcel data, the expert system would then select the superior proxy unit as the disaggregation technique for each block group. According to Maantay, Maroko, and Herrmann (2007, 88), “it is the performance of the tract-level disaggregation defines the proxy units used for each block group disaggregation, resulting in a final dasymetrically derived value individually tailored for each block group.”

From here, Maantay, Maroko, and Herrmann (2007) were able to compare the FAW method with the CEDS method. They estimated the differences of these two methods by creating a 150-foot buffer around a main road and gathered the block groups and tax lots that intersected that buffer. They also used the open space parcels as the “cookie cutters” for the parcels. To calculate the population impacted, they found the percentage of population of the area of the block group inside and outside the buffer zone. They did this for both the FAW method and the CEDS methods. This project followed this comparison, but instead of using a buffer around roads, it will calculate the percentage of affected parcels and block groups inside each SLR inundation.

Chapter 3 Methodology

GIS is a necessary tool to portray and spatially analyze the impacts of the total population from future SLR projections. A number of geoprocessing and spatial analysis tools were used in ArcGIS Pro to show where the total population will be impacted by several SLR projections. Editing the geodatabase through ArcGIS will be necessary because the data will become easier to work with and understand. As a by-product of editing the geodatabase, this project was able to statistically analyze, import, enhance, and process similar images to highlight areas of where and what SLR inundations will impact the attributes necessary for each mapping method. Then, the techniques on how to design the three mapping methods are described. By creating these maps for each SLR projection, this project was able to provide insights into the future impacts in Huntington Beach and Newport Beach. Also, equations to calculate for population were provided for the FAW and CEDS methods. Before this study describes how to make the maps, analyzing the data should be discussed first because the mapping methods need reliable and functioning data.

3.1. Research Design

Using GIS to analyze the population impacts caused by SLR in each city is necessary for the research and contributions to the spatial science literature. This study analyzes the impacted population numbers within all the possible SLR projections by using SLR datasets at high confidence provided by NOAA's Office of Coastal Management. The SLR datasets downloaded from NOAA are the one and four-foot GSLR projections and the two and six-foot RSLR projections that may occur by 2050 to 2100. In order to map the total population impacts caused by SLR, this study creates three dasymetric mapping techniques. The first technique is a novel form of dasymetric mapping, called Cadastral-based Expert Dasymetric System (CEDS). Then, the CEDS method is compared with the centroid-containment and FAW methods to show how CEDS is far superior in spatially locating impacted populations. These mapping methods will be creating maps of Huntington Beach and Newport Beach. By creating these mapping methods in two cities, this study shows the mapping differences of impacted populations in both highly and less urbanized areas.

3.2. Data Sources

To create the three mapping techniques and map the effected population from the SLR projections, it is necessary to gather suitable geospatial data. The geospatial data is shown in Table 4. The first step is to figure out all of the necessary SLR projections and describe the SLR data properties, as described in 3.2.1. Next, 3.2.2. provides information about how the American Community Survey creates the census block group dataset, as well as the block group's properties. Then, section 3.2.3. describes the process on how land use parcels are created, as well as the different land use classifications used for Huntington Beach and Newport Beach. Finally, section 3.2.4. describes how the assessor point data was created and its spatial properties. Also, in ArcGIS, all of the datasets in Table 4 are mapped in the NAD_1983_StatePlane_California_VI_FIPS_0406_Feetcoordinate system. It is necessary to describe the properties of the spatial datasets used in this project because the properties provide information about their usefulness to the study.

Table 4: Project Datasets

Datasets	Type	Scale	Precision	Accuracy	Fields	Source
Sea Level Rise Inundation (High Confidence)	Vector polygon	1:18,055	About 2 or more feet off	Estimated values because inundations are projections and aren't exact values	SLR code	NOAA – https://coast.noaa.gov/slrdata/
Assessor Data	Vector point	Cadaster	About 4 feet off, which is very precise	Could have 2 or more points in one parcel. Other than that, it's accurate	Number of housing units (HU)	www.boundarysolutions.com.
Land Use (LU)	Vector polygon	Parcels	Precise (could be about 2 ft off)	Very Accurate	2016 land use code, land use	SCAG – http://gisdata-scag.opendata.arcgis.com/datasets/8b0974afe5164f37999686021555329e_0 And Newport Beach data portal https://www.newportbeachca.gov/government/departments/city-manager-s-office/information-technology-city-division/gis-mapping/data-catalog
American Community Survey (ACS) Data	Vector polygon	Block group (BG) boundary	Precise (could be about 2 ft off)	Uses the 5-year estimate for 2018, so this is the most accurate	ID, 2018 total population, area per sq. mi.	ESRI's Business Analyst

3.2.1. Sea Level Rise Projections

As shown in Table 4, this study collects the SLR datasets from NOAA's Office of Coastal Management as shapefile polygons. Instead of using projections made by the IPCC (2019) or the Committee (2012), NOAA provides accurate representations of current and future SLR. The data is provided for each SLR inundation in feet or meters, in low and high confidences, and is relative to local Mean Higher High Water (MHHW). As explained by Berg (2016), MHHW is used because the National Ocean Service considers it as the best approximation of the threshold at which inundation can begin to occur. After collecting this data, this project downloaded four SLR datasets at the necessary inundation projections in Orange County. This project gathers the data in feet and high confidence of the MHHW. This project does not use the low confidence areas because, as explained in a technical report by the Office of Coastal Management in 2017, the low confidence has a very little chance of happening. They are also hydrologically unconnected areas that may flood based on how well the elevation data captures the area's drainage characteristics, which include canals, ditches, and stormwater infrastructure. However, the high confidence is portrayed as eighty percent correctly mapped flooded areas. These projected areas, at high confidence, are determined solely by how well the elevation data capture the area's hydro connectivity to the ocean. The MHHW is the average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch, which is about nineteen years (NOAA, 2017). The SLR inundations were also created by subtracting the NOAA VDATUM MHHW surface from the digital elevation model (DEM). Lastly, the spatial data of the SLR inundations are very precise. The SLR polygons are about two feet off, give or take, because NOAA's maps only represent the known error in the elevation data and tidal corrections and do not account for the natural evolution of the coastal landforms (NOAA, 2017).

3.2.2. American Community Survey

Another spatial dataset used in this project is the census block group dataset, which contains population attributes. The demographic dataset, used for all the mapping methods used in this project, is provided by ESRI in their Business Analyst tool. Also, this dataset contains the original American Community Survey (ACS), developed by the U.S. Census Bureau. The data this project examines is the ACS 2018 total population estimates, which is provided by the Census Bureau. This population data uses ACS's five-year estimates for total population in 2018. The five-year estimates and are created by collecting sixty months of data in 2018, between January 1, 2014 and December 31, 2018. The five-year estimates are used when examining populations at smaller geographies, like the block group. These estimates use the most current data in 2018 and are more reliable than the one-year, one-year supplemental and three-year estimates. The reason why these estimates are less accurate than the five-year estimates is because the one-year estimates collect twelve months of data and the three-year collects thirty-six months of data. Block group polygon boundaries are created using the US Census Bureau TIGER/Line 2018. Lastly, the fields to be analyzed in this dataset are the 2018 total population and the area. The area is in square miles in each block group.

3.2.3. Land Use Data of Huntington Beach and Newport Beach

Land use parcels are used in this study to analyze population impacted by SLR at a smaller scale than the block group. These datasets are used for the FAW method and the CEDS method. Also, different datasets from different sources are used for each city. The Huntington Beach land use dataset is collected from the SCAG because Huntington Beach does not have its own data. The data was downloaded as a shapefile and is made of 51,952 land use parcel polygons. This study uses SCAG's 2016 land use dataset, updated as of November 2018, which is the most recent version. The attributes included in the dataset are the land use classifications, which the land use codes in numbers, as shown in Table 5. The land use codes for residential areas in Huntington Beach include the 1110 to 1113 single family residential codes, 1120 to 1125 multi-family residential codes, 1130 mobile homes and trailer parks codes, 1140 mixed residential codes, and the 1600 mixed residential and commercial code. Since this project uses land use codes for the year 2016, some of the data is old and could have changed. Most of the classifications are accurate, so this project considered the data to be accurate enough to use.

Table 5: SCAG Land Use Codes for Huntington Beach

Residential Types	Land Use Code	Land Use Description
Single-Family Residential	1110	Single Family Residential
	1111	High-Density Single Family Residential (9 or more DUs/ac)
	1112	Medium-Density Single Family Residential (3-8 DUs/ac)
	1113	Low-Density Single Family Residential (2 or less DUs/ac)
Multi-Family Residential	1120	Multi-Family Residential
	1121	Mixed Multi-Family Residential
	1122	Duplexes, Triplexes and 2- or 3-Unit Condominiums and Townhouses
	1125	High-Rise Apartments and Condominiums
Mobile Homes and Trailer Parks	1130	Mobile Homes and Trailer Parks
Mixed Residential	1140	Mixed Residential
Mixed Residential and Commercial	1600	Mixed Residential and Commercial

Source: Southern California Association of Government (2017)

Newport Beach's land use parcels are more accurate and recent than the SCAG data because Newport Beach's Information System department creates and edits the attributes weekly. This project uses Newport Beach's 2020 land use data and accounts for the residential areas. The residential areas that the spatial data projects include single family residential attached and detached, two family unit residential, and multiple family residential attached and detached. The single-family residential areas contain dwellings that are on a single lot and do not include condominiums or cooperative housing, as explained in the general plan for Newport Beach. Also, the two-family residential areas include duplexes and townhomes. There are two multiple family residential areas. One category contains both attached and detached dwelling units and the other category contains only residential areas. Attached dwelling units are dwelling units that are attached to another dwelling unit by a wall, floor, or ceiling that separates heated living places. These would include an apartment over the garage, a tiny house in the backyard, and a basement apartment. Also, detached dwelling units contain one structure with no other units on the property.

3.2.4. Assessor Data

Another geospatial dataset that is analyzed for the CEDS method in this study is the assessor tax data. This dataset was free, and created by Boundary Solutions Inc. in 2017. The dataset is point data and is accurate up to four feet. The attribute that is important in this dataset is the number of housing units (HU). Some points, in this project, are not located in the right position; however, this inaccuracy is not enough to where it could affect the analysis of the data. Some of the points are not located in the right parcel, so they are not used in the project. There are not enough assessor points that do this, so they don’t affect the analysis in this project. Also, 63,001 assessor data points are in Huntington Beach, and 56,905 assessor points in Newport Beach.

3.3. Data Processing

This section describes how the geospatial data is integrated into ArcGIS in order to create and analyze the necessary SLR inundations and mapping methods. In 3.3.1 this study describes how to create and project the SLR inundations in the study areas. Section 3.3.2 describes how to prepare the land use data and assessor data for the three mapping methods. Then, section 3.3.3 describes how to make the centroid-containment method. Additionally, section 3.3.4 describes how to create the FAW method. Finally, section 3.3.5 describes how to create the CEDS method.

3.3.1. Mapping Sea Level Rise

The first step in creating an SLR analysis is the process of creating an SLR dataset. This project uses the high confidence projections of the GSLR, one and four feet, and the RSLR Inundations, two and six feet, in Huntington Beach and Newport Beach. To construct these datasets in these cities, the datasets are clipped within the Huntington Beach and Newport Beach boundary. The clipped SLR datasets include part of the ocean, shoreline, and the wetlands in both cities. The results are four SLR inundation datasets for both cities, as shown in Figure 3.

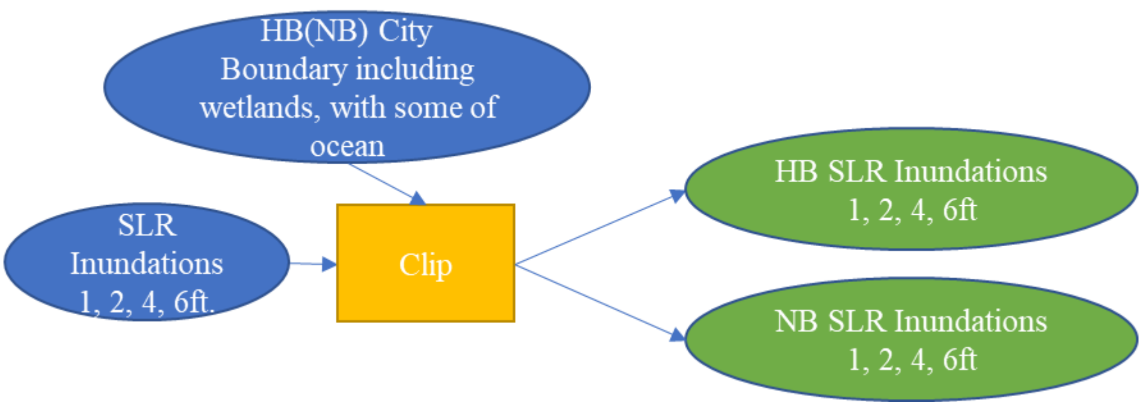

Figure 3: Sea Level Rise Inundation Model

The Huntington Beach GSLR and RSLR projections are shown on the left of Figure 4. Additionally, Newport Beach also exhibits the same GSLR and RSLR projections, shown on the right of Figure 4. The boundaries for each city are also edited to show some of the ocean, so the aggregation of the data could obtain the shoreline regression in each city. Showing the shoreline regression is important to analyze, so this project can find how the residential areas and block group data would be impacted at each SLR inundation.

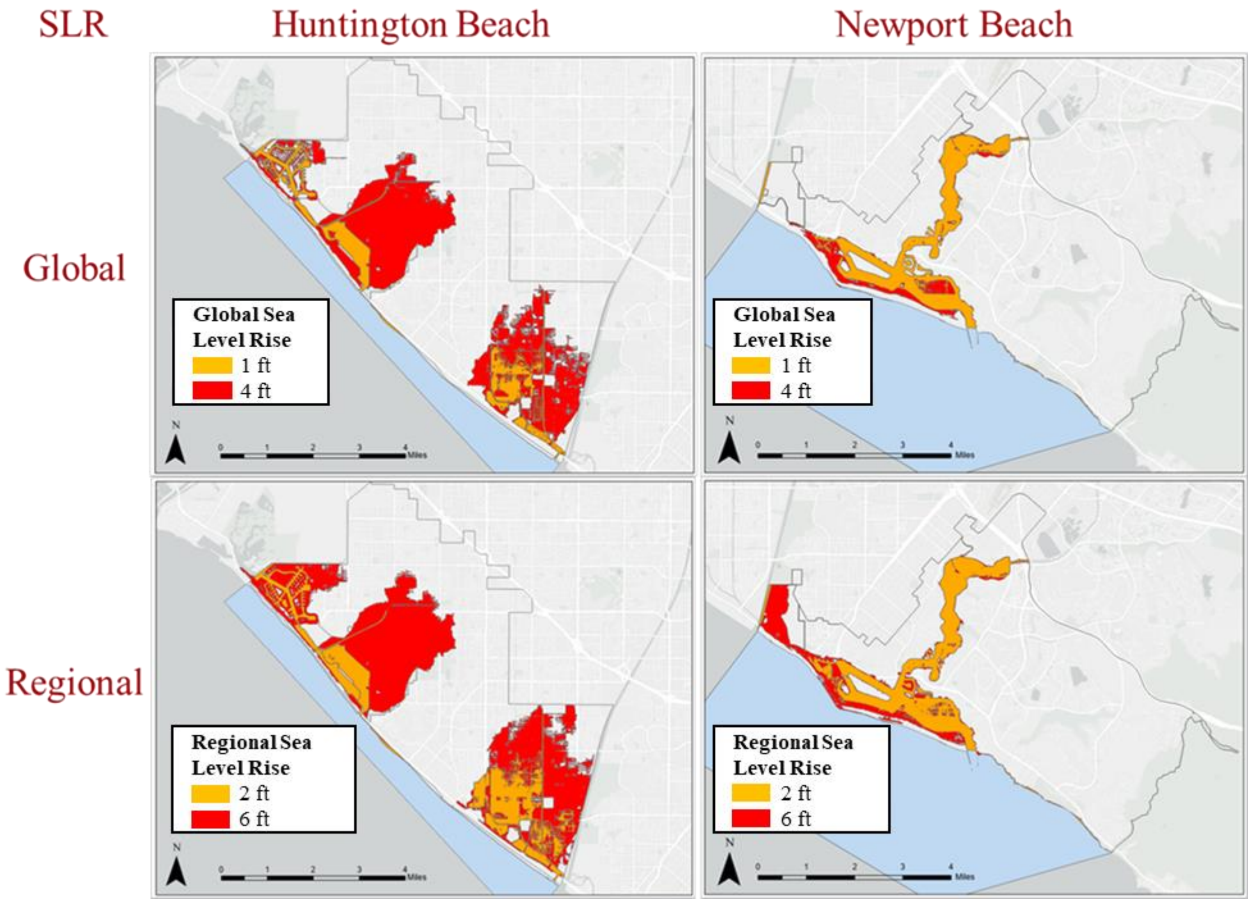

Figure 4: Project Site Maps of Projected Global and Regional Sea Level Rise

3.3.2. Preparing the Land Use and Accessor Data

In order to construct the three mapping methods correctly, the land use and assessor data has to first be prepared. For Huntington Beach, the attribute that is used to analyze the land use parcels includes the 2016 land use codes for the residential areas. The Newport Beach land use parcels includes the land use attribute for the city’s residential areas. The assessor dataset, for both Huntington Beach and Newport Beach, are points that include the number of housing units attribute. All of these datasets are created to analyze the population impacts created by SLR.

To prepare these datasets, as shown in Figure 5 this project first spatially joins the land use parcels and the assessor points, in order to create the tax lots. Next, the Add Field tool was used to create the adjusted residential area in the tax lots. Then, the Select Layer by Attributes tool was used to find the residential land use parcels in each city. To find the residential parcels in Huntington Beach, this project searched for the land use codes shown in Table 6. For Newport Beach, this project used residential land use information, which is different from the land use codes of Huntington Beach (Table 6). Finally, the spatial join function was used to combine the tax lots and the block groups for each city. By combining these datasets, this project ended up with two new residential tax lot datasets that are aggregated in each census block group. Table 6 shows the total number of the residential land use types that are impacted by the SLR projections in each city. The total number of residential land use types were found by counting the number land use polygons affected by each SLR projection. These datasets are used in the FAW and CEDS mapping methods for population in both cities.

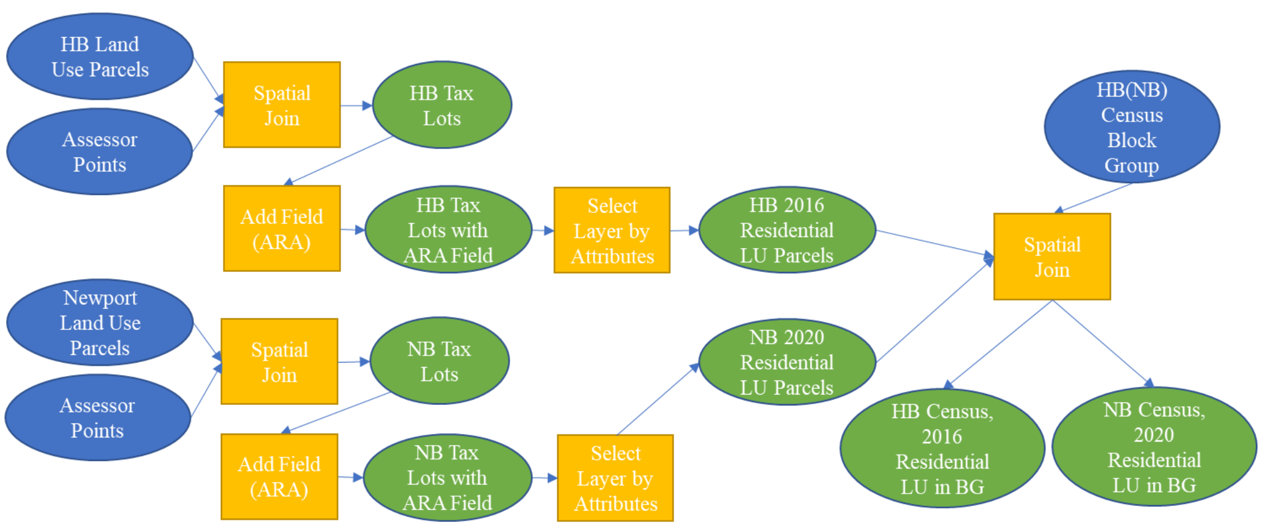

Figure 5: Data Preparation Workflow

Table 6: Residential Land Use Impacts in Huntington Beach and Newport Beach

City	Land Use Type (Code)	1ft SLR	2ft SLR	4ft SLR	6ft SLR	No SLR
Huntington Beach	Single Family Residential (1110)	3,222	5,081	16,021	19,416	40,421
	Multi-Family Residential (1120)	17	23	127	492	3,555
	Duplexes, Triplexes and 2- or 3-Unit Condominiums and Townhouses (1122)	256	411	729	860	2,462
	Medium-Rise Apartments and Condominiums (1124)	0	0	1	1	1
	Mobile Homes and Trailer Parks (1130)	2	311	316	320	347
	Mixed Residential and Commercial (1600)	0	0	1	1	10
	Total Residential Parcels	3,225	5,826	17,195	21,090	46,796
Newport Beach	Single Unit Residential Attached	-	-	-	-	1,882
	Single Unit Residential Detached	763	889	1,406	2,424	16,053
	Multiple Residential	27	37	130	139	692
	Multiple Residential Detached	-	-	-	-	29
	Two Unit Residential	828	1,971	2,827	3,321	5,014
	Total Residential Parcels	1,618	2,897	4,363	5,884	23,040

3.3.3. Mapping the Centroid-Containment Method

First, this project creates the previously used mapping methods that analyzed population impacts caused by SLR. The centroid method, as shown in Figure 6, is the simplest method that creates centroids from census block groups in Huntington Beach and Newport Beach. These centroids are points created in the geometric middle of the polygons and have all the attributes that the block group has. In order to create the centroids, Figure 6 shows that the Polygon to Centroid geoprocessing tool is used to create a centroid in each block group. The attributes include the number of HUs, polygon IDs, area per square mile, and the 2018 total population. Then, the intersect geoprocessing tool is used to gather the centroids that are intersecting with each SLR inundation. After this step is finished, Huntington Beach includes four centroid datasets interesected at one, two, four, and six feet. Newport Beach includes three centroid datasets intersected at two, four and six feet. The centroids also gain a new attribute field that includes the SLR polygon's IDs for each inundation. No centroids are impacted at one foot because the one foot SLR inundation doesn't intersect any points in Newport Beach. Finally, the Add Join tool is used to join the impacted centroids to the block group that have the same ID code. Once this workflow is completed, there is one new block group dataset for each city, but three new attribute fields are provided for each intersected centroid. The new attribute fields include: the SLR polygon IDs, 2018 total population, and area per square mile. For instance, Huntington Beach contains twelve new attribute fields, and Newport Beach contains nine new attribute fields.

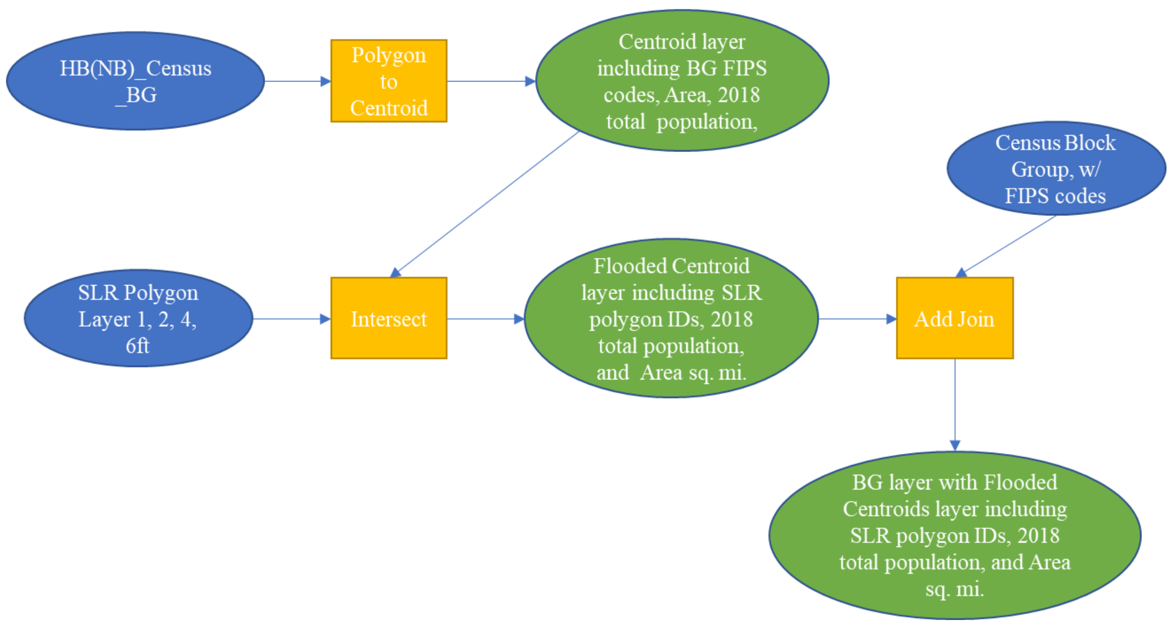

Figure 6: Centroid-Containment Method Workflow

This method is the least effective because if the SLR inundations intersect with the polygons but not the centroid, the data is not gathered. By not intersecting with the centroid, there may be population data that is not accounted for. Also, if the SLR inundation does intersect with the centroid, then it gathers all of the population information from that block group even if the inundations do not impact any residential areas.

After creating the new block group dataset, this project spatially projects the population density impacted at each SLR inundation in both cities. To create the population density, this project created a population density field to analyze the data thoroughly. After creating a new field, the Calculate Field tool was used and then selected the Arcade option. From here, 2018 total population was divided by area per square mile. This equation created choropleth maps for the impacted 2018 total population per square mile for each inundation in each city. The choropleth maps are created to show the same ranges of population density in order to show how the block groups change over time and space. To create the same population density ranges, the CEDS population density at six feet is analyzed and the five population density ranges for each mapping method is provided for both cities.

3.3.4. Mapping the Filtered Areal Weighting Method

The other dasymetric mapping method used in this project is the FAW method. This method is more accurate than the centroid method because the FAW method uses the census block groups and residential land use parcels. The block groups and residential land use parcels are used for Huntington Beach and Newport Beach. The same SLR inundations are used in this dasymetric mapping method. As shown in Figure 7, the first step is to create the total amount of residential parcels in block groups. To perform this step, this project utilizes the Intersect tool for the block group polygons in Huntington Beach and Newport Beach that intersect with the residential land use parcels. This step integrates the correct block group ID codes into all residential land use parcels. Then, the Dissolve tool is used to find the residential parcels aggregated by the ID codes. In the Dissolve tool, the count for residential land use codes is chosen. This step provides one residential polygon per block group, with the total number of residential units in it. Next, the Add Field tool is used to create a total area per square mile field.

To calculate for the total area of land use parcels in each block group, the Calculate Geometry Attributes tool is used. In this pane, the area per square mile is chosen for area and NAD_1983_StatePlane_California_VI_FIPS_0406_Feet is chosen for the coordinate system, which is used for all three methods. Lastly, the add join tool is used in order to join the dissolved residential land use parcels into the block group by matching the ID codes. By following this process, this project created the total amount of residential areas in the block group areas. This process is useful to calculate for the total impacted population by SLR.

The next process, shown in Figure 7, is to find the residential land use parcels in each block group that are impacted by each SLR inundation. The first step is to use the intersect tool for the residential parcels in each block group that intersect with the four SLR inundations. This step creates four residential parcel datasets within each SLR inundation, with the SLR polygon IDs, that are in each block group, categorized by the corresponding block group ID codes. From here, the Dissolve tool is used to create one residential polygon in each block group that is intersected by each SLR inundation. In the Dissolve tool, the sum of residential units impacted in each block group that is intersected at each SLR inundation is calculated by selecting count of land use codes in the statistics section. Next, the Add Field tool is used to create a field about the area per square miles for the four SLR inundated areas in each city. Then, the Calculate Geometry Attributes tool is used to calculate the area per square miles for each field. In the geoprocessing pane, under area, area per square miles is chosen and the NAD_1983_StatePlane_California_VI_FIPS_0406_Feet was chosen under the coordinate system. After this step, this newly created field, in each dissolved dataset, shows the RUs area per square miles impacted by each SLR inundation in each block group. Lastly, the add join tool is used to join the residential flooded parcels into the block groups of Huntington Beach and

Newport Beach, by using the correct ID codes. This step creates twelve new attributes in the block group for both Huntington Beach and Newport Beach. Each block group obtains entities that provide the following data: the areas of impacted RUs at each SLR inundation, the percent of RUs affected at each SLR inundation, and the total population impacted at each SLR.

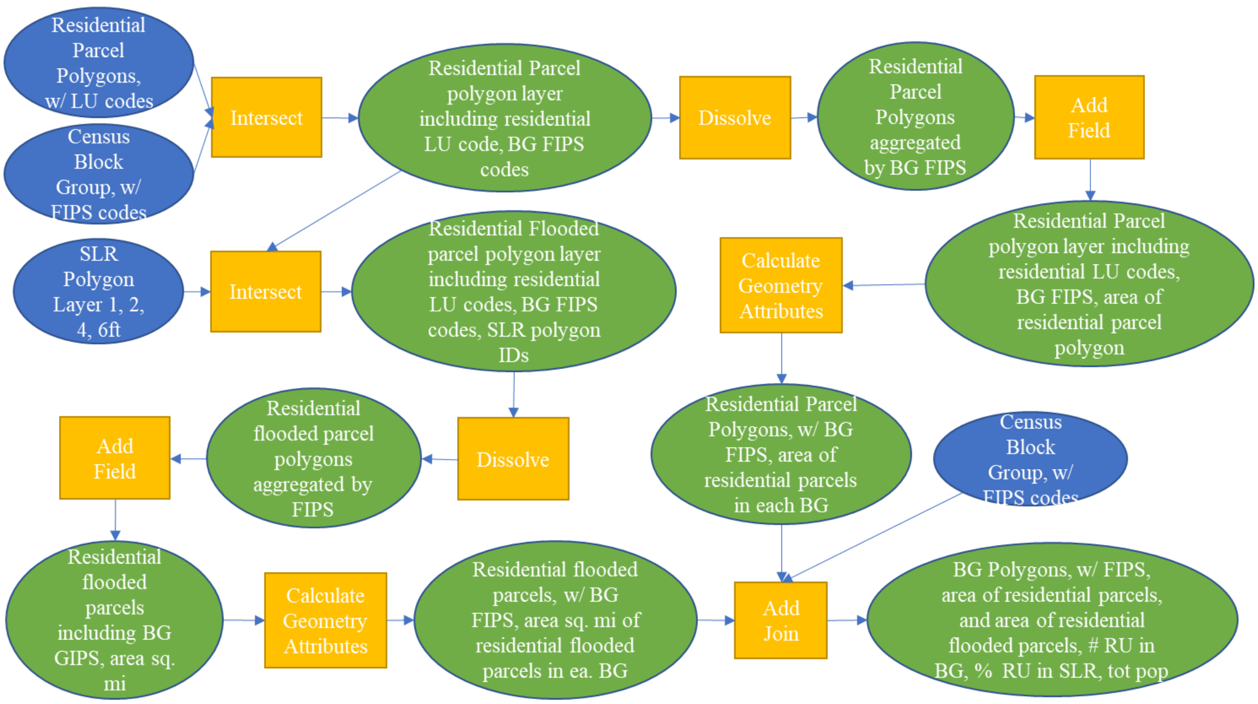

Figure 7: Filtered Areal Weighting Method Workflow

Finally, the next process in creating the FAW method is to find the total population impacted by each SLR inundation in each block group. To calculate it, this project uses Equation 1, which is based on Maantay, Maroko, and Herrmann's (2007) general equation to solve for dasymetrically derived populations:

$$POP_1 = POP_c * U_1/U_c \quad (1)$$

From this equation, this project's first step is to find the percentage of the impacted RA in each block group by calculating for U_1/U_c. U_1 is equal to the impacted RA by each SLR in each block group, and U_c is equal to the total RA in each block group. To solve for the U_1/U_c equation spatially in GIS, a percent field for each SLR inundation is created. Then, the Calculate Field tool is used. In this tool, the Arcade is selected as the script type. From here, the impacted RA fields are divided by the total RA fields. The result comes out to be the percentage of impacted RA fields for each block group.

After solving for the percentage of RA, the final step is to solve for POP_1, which is known as the total population impacted in each block group for this project. The Add Field tool is used again to create the total population impacted in each block group field. To manipulate for the total population, the Calculate Fields tool is used again to multiply the block group's 2018 total population field, shown in Equation 1 as POP_c, by the percentage of impacted RA fields. Finally, this tool provides the estimated total population impacted by the SLR inundations in each block group.

Additionally, since the total population is found, the population density of the affected population needs to be calculated. In order to construct a choropleth map, the population density fields at each inundation need to be created by using the Add Field tool. By adding the new fields, four new population density attributes are created at each inundation for each city, so eight new fields in total. Then, the Calculates Field tool is used in each field by dividing the estimated total population impacted field by the area. After running this tool, a choropleth map is created to show the estimated total population impacted per square foot.

3.3.5. Mapping the Cadastral-based Expert Dasymetric System

Finally, the most accurate method created at the parcel scale is the CEDS method. The CEDS is created by using the block groups, Huntington Beach 2016 residential land use parcels, Newport Beach residential land use parcels, assessor point data, and the same SLR inundations. Some of the important attributes in the tax lot parcels that is used in the method is the number of HUs, and land use codes. Tax lots are created by joining land use parcels with the assessor point data. As shown in Figure 8, the CEDS method follows the workflow described by Maantay, Maroko, and Herrmann (2007). The first step in this process is to combine the tax lots with the block group data by using the Intersect tool. Then, the combined data is intersected with the SLR inundations in each block group by using the Intersect tool. By utilizing the same tool twice, there are five new tax lot datasets in each city. The datasets contain one total tax lots in each block group and four tax lots that intersect with each SLR inundation categorized by block group. The attributes from the SLR data are the SLR codes. Also, the necessary attributes used in the block group includes the block group ID, 2018 total population, and area in square miles. Next, the Dissolve tool is used finding the sum of HUs in each block group for both the total parcels in the census block groups and the parcels impacted by SLR in each block group. However, using the sum of number of HUs was not an option, so this project has to find the number of impacted HUs at each inundation and the total number of HUs in each block group by selecting the taxlots in each block group and counting them. From here, use the ID codes to correctly use the add join tool to join the total and impacted tax lots with block groups. After processing this step, this project ends up with the total number of HUs in each block group, the number of impacted HUs in each SLR inundation within the block group. Lastly, the Add Field tool is used to create eight new fields for four types of SLR inundations in each city. The fields include the percent of impacted number of HUs in each block group, and the total population fields in each block group.

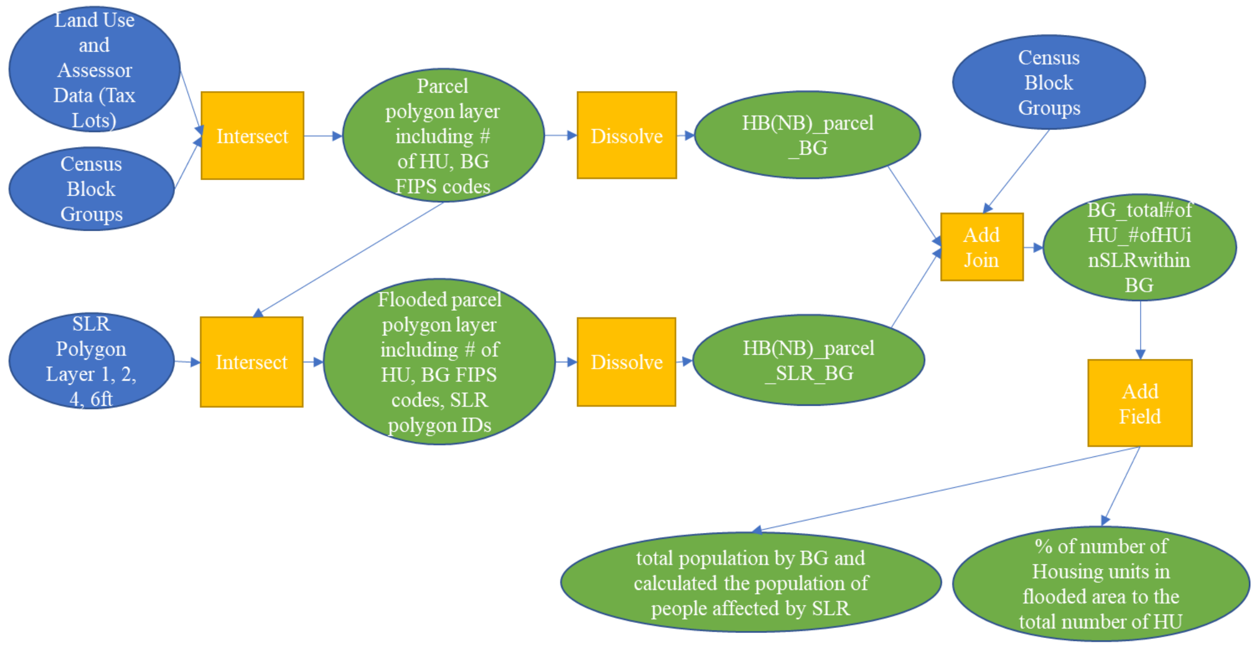

Figure 8: Cadastral-based Expert Dasymetric System Workflow

This project solves for the percent of impacted number of HUs in each block group, and the total population impacted in each block group by using Equation 2. This equation resembles Maantay, Maroko, and Herrmann's (2007) general equation to solve for dasymetrically derived populations:

$$POP_2 = POP_d * U_2/U_d \qquad (2)$$

From this equation, this project's first step is to find the percentage of the impacted number of HUs in each block group by calculating for U_2/U_d. U_2 is equal to the sum of impacted HUs by each SLR in each block group, and U_d is equal to the total number of HUs in each block group. To solve for the U_2/U_d equation spatially, a percent field for each SLR inundation is created. Then, the Calculate Field tool is used. Again, just like the FAW method, the Arcade script type is selected in the Calculate Field geoprocessing tool. From here, the sum of impacted HUs at each inundation is divided by the total number of HUs in each block group. The result comes out to be the percentage of impacted HU for each block group.

After solving for the percentage of the number of HUs, the final step is to solve for POP_2, which is known as the total population impacted in each block group. To estimate the total population, the Calculate Fields tool is used again to multiply the census block group's 2018 total population field, shown in Equation 2 as POP_d, by the percentage of impacted number of HUs fields. Finally, this tool provides the estimated total population impacted by the SLR inundations in each block group.

Additionally, after the total population is found, the population density of the affected population needs to be found. In order to construct a choropleth map, the population density fields at each inundation need to be created by using the Add Field tool. By adding the new fields, four new population density attribute fields are included within each inundation for each city, so eight new fields in total. Then, the Calculates Field tool is used in each field by dividing the estimated total population impacted field by the area. After running this tool, a choropleth map is created to show the estimated total population impacted per square foot. After performing these steps for the CEDS method in Huntington Beach and Newport Beach, the most accurate population impacts are found for each city.

Chapter 4 Results

A large amount of SLR impact results are discovered in each method and for each city by 2050 to 2100. Chapter 3 explains three different dasymetric methods and the estimation of the population affected by SLR. This chapter provides each mapping result. Then, the maps are analyzed to show the population impacts from the 2050 and 2100 GSLR projections in both cities. These maps are also analyzed to show the population impacts from the 2050 and 2100 RSLR projections for both cities. Finally, this chapter compares the mapping methods by the year in which the SLR is projected to impact the two cities. The results generated from these dasymetric mapping methods in 2050 and 2100 answer the questions asked in Chapter 1. The first objective is to find the impacts on the population at each SLR projection for each city. Next, this study analyzes the maps and their statistics within each city's SLR projections in order to find the most vulnerable areas. Additionally, the mapping methods are compared by year to show how the results are different by year and for each city.

In order to answer these questions, Chapter 4 analyzes the three mapping techniques in each city within the global and regional projections. From the analysis generated at the global and regional projections, further results are provided for 2050 and 2100. In section 4.1, the results for the three mapping methods are shown for each of the global and regional SLR projections in Huntington Beach. This section also describes each of the maps, then compares them by the projection. Section 4.2. provides and analyzes the mapping methods for Newport Beach the same way for Huntington Beach.

4.1. 2050 and 2100 Mapping Results for Huntington Beach

Through the process of analyzing and comparing the mapping methods generated for Huntington Beach, this study clearly provides results for how the mapping methods are different and show where the city is most vulnerable at each projection and city. As shown in Figure 9, each of the dasymetric mapping methods for Huntington Beach categorized by the SLR projection in ascending order and by mapping method. Additionally, all of these maps are created with the ranges formed from the CEDS map impacted at six-feet, shown in Figure 10. From here, this study clearly analyzes how the city is impacted differently by mapping method and by year of the SLR projection. First, this study explains each mapping method result created at each inundation. Then, the maps are compared by method and by year of the SLR inundations. These comparisons provide results about how the mapping methods differ by year and to show how the CEDS method is superior to the others.

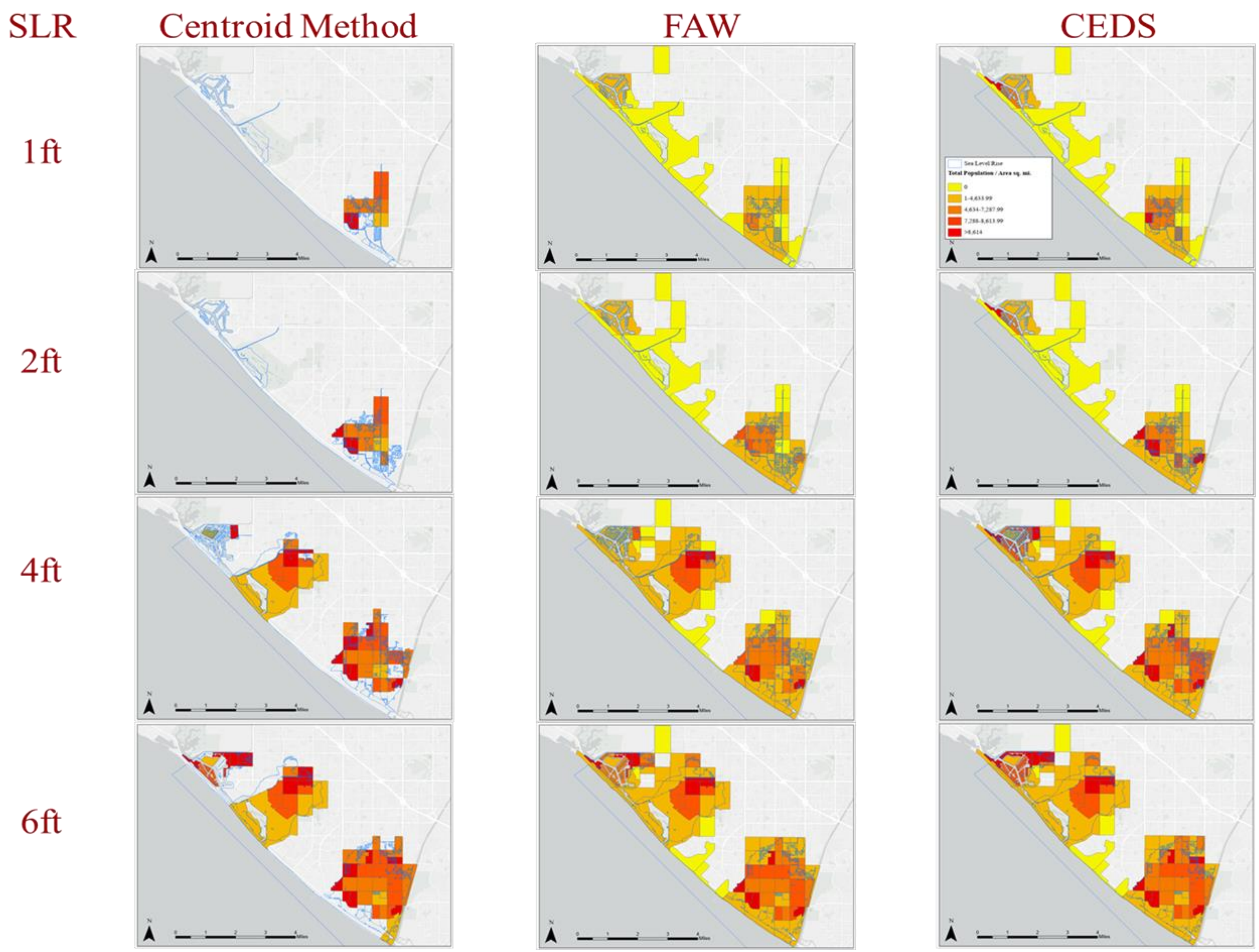

Figure 9: Huntington Beach Mapping Methods

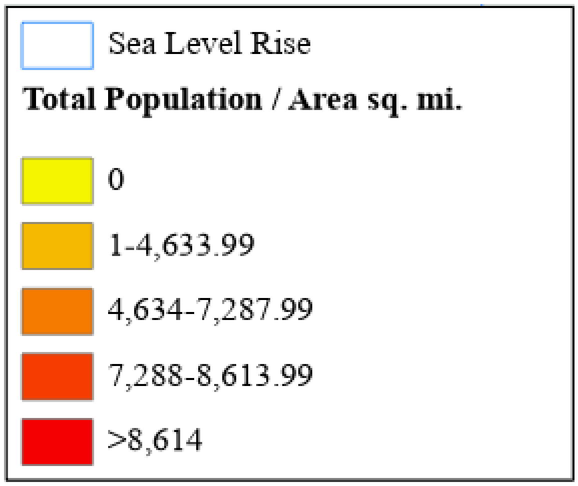

Figure 10: Population Density Ranges for Study Areas

Even though the centroid method is the least effective and accurate dasymetric mapping method for finding population impacts from the GSLR and RSLR projections, this project still finds several impacts on the population in each city. As stated in Chapter 3, the centroids were joined into the block groups. In Figure 9, the first centroid map shows the population density impacts in Huntington Beach from the 2050 one-foot GSLR projection. This map shows the impacts of the population density located in the southern most area of Huntington Beach, with no connection to the ocean. While the centroid map at the 2050 two-foot projections impacts the population density the same way as the one-foot projections, this centroid map portrays more impacts to the block groups in the southern area. By 2100, Figure 9 shows the centroid map intersected at the four-foot GSLR inundation and this map shows most of the population density impacted both in the southern and northern areas of. In the most northern area, the population density portrays impacts on the block groups caused by the Huntington Beach bay and the Seal Beach wetland. Just south, the population is largely impacted by the Bolsa Chica wetland. The map also portrays the population density to be mostly impacted in the southern most area of Huntington Beach, but the block groups are still not connected to the ocean in the southern area. Also, Figure 9 shows the population density impacts for Huntington Beach in 2100, but for the six-foot RSLR projection. This map shows more of the block groups impacted in the same areas as the four-foot projections. Within this projection, the southern area finally shows connectivity to the ocean. This map also shows the southern area to have more impacts than the northern areas.

Next, the population density results for the FAW method are analyzed the same way from the same projections as the centroid method. As stated in Chapter 3, the FAW method results for the projected 2050 and 2100 GSLR and RSLR inundations in Huntington Beach the residential areas were joined into the block groups. In Figure 9, these maps show all of the block groups impacted by the SLR projections. The yellow block groups contain zero population densities, which means none of the residential areas are impacted in the yellow areas. In the FAW map within the 2050 one-foot GSLR projection, the block groups are shown along the coast and the population impacts are located in the southern and northern areas, with most of the population density impacted in the southern area. The downtown area is also inundated, but with zero population density impacts. This could mean that the shoreline is affected, but not any of the residential areas. While the 2100 two-foot RSLR projections are shown to impact the same areas as the one-foot projections in the FAW method, more block groups are affected, and more population density impacts are shown in the southern area and in the Huntington Harbor. By 2100, the FAW map affected within the four-foot GSLR inundation shows more block groups impacted all along the coast, with most of the population density impacts in the southern areas, as well as near the Bolsa Chica wetlands. Around the Huntington Harbor, more impacts are shown than in the one and two-foot projections. However, the FAW map intersected with the six-foot RSLR projection affects even more block groups. The population density impacts are also affected greater than the four-foot projections in the southern area and around the Huntington Harbor and Bolsa Chica.

Finally, the results from the CEDS method are found for the 2050 and 2100 GSLR and RSLR projections in Huntington Beach, and show the same impacted block groups as the FAW maps, but with different population density impacts. As stated in Chapter 3, the residential units were joined into the block groups. In Figure 9, the results of the CEDS map intersected at the one-foot projection show population impacts to be more than the FAW method in the southern area and around Huntington Harbor. The Seal Beach wetlands can also impact the areas around Huntington Harbor. From the CEDS map intersected by the two-foot RSLR projection, the map shows the most accurate population impacts from the most recent regional SLR projection. The population density impacts in the southern area, and around Huntington Harbor show the greatest impacts of the three methods and by 2050. By 2100, the CEDS map at four-feet depicts an abundance of population impacts in both areas, with the greatest impacts to be in the Huntington Beach Harbor. However, the CEDS map impacted in the six-foot RSLR projection shows most of the population density impacted in the southern area, around Huntington Harbor, and north east of the wetlands. Still, the downtown area shows zero population affects. All of these maps are also compared based on SLR projection type and year.

The maps created for each method are compared based on the height of the SLR projection in Huntington Beach. For instance, Figure 9 shows that all of the mapping methods impacted by the 2050 one-foot GSLR and two-foot RSLR projections. The block groups in the centroid methods are not connected to the ocean, but the block groups in the FAW and CEDS maps are connected even though some do not have population density impacts. For the FAW and CEDS maps, the greatest population impacts are shown in the southern areas and the least population impacts on the northern areas. While the centroid map shows greater impacts from the two-foot projection, only the southern area of Huntington Beach is affected.

Next, the mapping methods in Huntington Beach are analyzed to compare the impacted areas within both of the 2100 RSLR projections. In this case, Figure 9 shows all of the mapping methods in the 2100 four-foot GSLR and six-foot RSLR projections that have the greatest population impacts for all of Huntington Beach. The block groups in the centroid methods aren't connected to the ocean in the northern most and southern areas at four-feet, unlike the FAW and CEDS maps. However, the southern area finally shows block groups connected to the ocean in the centroid map. Additionally, the block groups in the centroid methods aren't connected to the ocean in the northern most area at six-feet, but the FAW and CEDS maps are connected to the ocean. Of the impacted block groups, both of the CEDS maps show greater population impacts in the northern and southern areas than the FAW maps. In the northern and southern areas, the CEDS methods contains more block groups with population density greater than one than the FAW maps. Overall, the CEDS maps show more population density impacts than in the other two methods.

Furthermore, this section continues to analyze each mapping method, by explaining the results of the summary statistics from Table 7. This table shows all of the necessary attributes impacted by the SLR projections in each mapping method created for Huntington Beach. In section 4.1.1, the results of the impacted data in Huntington Beach are described for the centroid method within the 2050 and 2100 GSLR and RSLR projections. 4.1.2. describes the many results found in the FAW method for Huntington Beach. Lastly, 4.1.3 describes the results from the CEDS method at each SLR inundation in Huntington Beach.

Table 7: Huntington Beach Mapping Method Results

Mapping Method	Sea Level Rise	Total # of Block Groups	Total Population	Total Affected Area (sq. mi.)	# of Block Groups with Population 0	Total Affected Residential Area	# of Hous-ing Units
Centroid-Containment	1ft	8	12,682	1.756	n/a	n/a	n/a
	2ft	11	15,952	2.251	n/a	n/a	n/a
	4ft	35	48,617	8.806	n/a	n/a	n/a
	6ft	50	69,806	11.464	n/a	n/a	n/a
Filtered Areal Weighting	1ft	33	6,193	n/a	15	0.35	n/a
	2ft	38	12,467	n/a	12	0.82	n/a
	4ft	66	49,440	n/a	9	3.46	n/a
	6ft	72	69,181	n/a	6	4.74	n/a
Cadastral-based Expert Dasymetric System	1ft	33	13,008	n/a	13	n/a	6,013
	2ft	38	22,428	n/a	11	n/a	10,184
	4ft	66	61,354	n/a	7	n/a	26,038
	6ft	72	75,975	n/a	6	n/a	31,312

4.1.1. Further Centroid-Containment Method Results for Huntington Beach

By examining the centroid method in Table 7, the summary statistics provide more in-depth results for each centroid map in Huntington Beach. Within the 2050 one-foot GSLR projection, the results show that a total of eight block groups with a total area of 1.756 square miles may be impacted. Also, 12,682 of the total population may be impacted within the 2050 one-foot GSLR projection. However, the centroid method impacted at the 2050 two-foot RSLR projection shows a total of eleven block groups with an area of 2.251 square miles that may be impacted by 2050. Additionally, 15,952 people may be impacted by the two-foot projection. Furthermore, the impacts by 2100 show that a total of thirty-five block groups with an area of 8.806 square miles may be impacted within the four-foot GSLR projection. The total population within these block groups shows that 48,617 people may be impacted. Lastly, Table 7 shows the results from the six-foot RSLR projection, in which a total of fifty block groups with a total area of 11.464 square miles may be impacted by 2100. Also, 69,806 people may be impacted by the six-foot SLR projection.

4.1.2. Further Filtered Areal Weighting Method Results for Huntington Beach

Next, the results are analyzed the same way for the FAW method as performed for the centroid method. The summary statistics of the impacted block groups are provided for each of the FAW maps intersected within the 2050 and 2100 SLR projections (Table 7). Within the 2050 one-foot GLSR projection, the results show thirty-three affected block groups, with a total residential area of 0.35 square miles that may be impacted. Also, 6,193 of the total population may be impacted. Of the thirty-three intersected block groups, fifteen of them contain population impacts of zero. On the other hand, the results within the two-foot RSLR projection show impacts to thirty-eight block groups with a total residential area of 0.82 square miles that may be impacted by 2050. In those thirty-eight block groups, 12,467 of the total population may be impacted, and twelve of those block groups contain zero population impacts. By 2100, the results at the four-foot GSLR projection show that sixty-six block groups may be impacted, with impacts to a total residential area of 3.46 square miles. Additionally, 49,440 of the total population may be impacted by 2100. Of the sixty-six intersected block groups, nine of them contain population impacts of zero. Finally, the results at the six-foot RSLR projection show seventy-two block groups and a total residential area of 4.74 square miles that may be impacted by 2100. Also, within the intersected block groups, six of them contain zero population impacts, and 69,181 of the total population may be affected.

4.1.3. Further Cadastral-based Expert Dasymetric System Results for Huntington Beach

This section reports the results of the CEDS method, which is the most effective and most accurate dasymetric mapping technique of the three methods in this study. The results are found the same way as the other methods but on a much smaller scale. Table 7 shows the summary statistics of the impacted block groups for the CEDS method, which informs the highest amount and most accurate population estimations compared to the other two mapping methods. The results at the 2050 one-foot GSLR projection may impact thirty-three block groups, with thirteen of them containing zero population impacts. In those thirty-three block groups, 13,008 of the total population, as well as the total number of housing units, may be impacted. The population in the CEDS, the total number of housing units was also found in each SLR projection. The one-foot projection may affect 6,013 housing units in Huntington Beach. However, the results at the two-foot RSLR projection may impact thirty-eight block groups, with impacts to a total population of 22,428, and may impact 10,184 housing units. Of the intersected block groups, eleven of them contain zero population impacts. Then, the results within the 2100 four-foot GSLR projection show that sixty-six block groups that may be impacted. Within those sixty-six block groups, 61,354 of the total population may be affected, and seven of them contain zero population impacts. Additionally, a total of 26,038 impacted housing units may be within the four-foot projection. Furthermore, the results at the 2100 six-foot RSLR projection shows possible impacts to seventy-two block groups, with six of them containing zero people affected. Within those seventy-two block groups, 75,975 of the total population, as well as a total of 31,312 housing units, may be impacted.

4.2. 2050 and 2100 Mapping Results for Newport Beach

While many different impacts exist within Huntington Beach, the mapping methods for Newport Beach show quite a few different effects on the population. In order to provide a full representation of how each city is impacted by SLR projections, an analysis of the mapping methods generated from the global and regional projections fulfill all possible SLR impact scenarios. For this section, the results are found from each of the dasymetric mapping methods intersected within the 2050 and 2100 SLR projections for Newport Beach. Specifically, this project locates and analyzes the areas of vulnerability, as well as showing differences between the methods at each year. To complete this goal for Newport Beach, this project starts by using Figure 11 to analyze and describe the resulting maps the same way as done for Huntington Beach. Figure 11 is created the same way as for Huntington Beach, except there is no map for the centroid method at the one-foot GSLR projection. Then, the mapping methods are compared at each inundation, similar to the comparison of Huntington Beach. These comparisons provide results about how the mapping methods differ by year and show where the most vulnerable areas are in Newport Beach. The maps are created with the same range as created for Huntington Beach (see Figure 10).

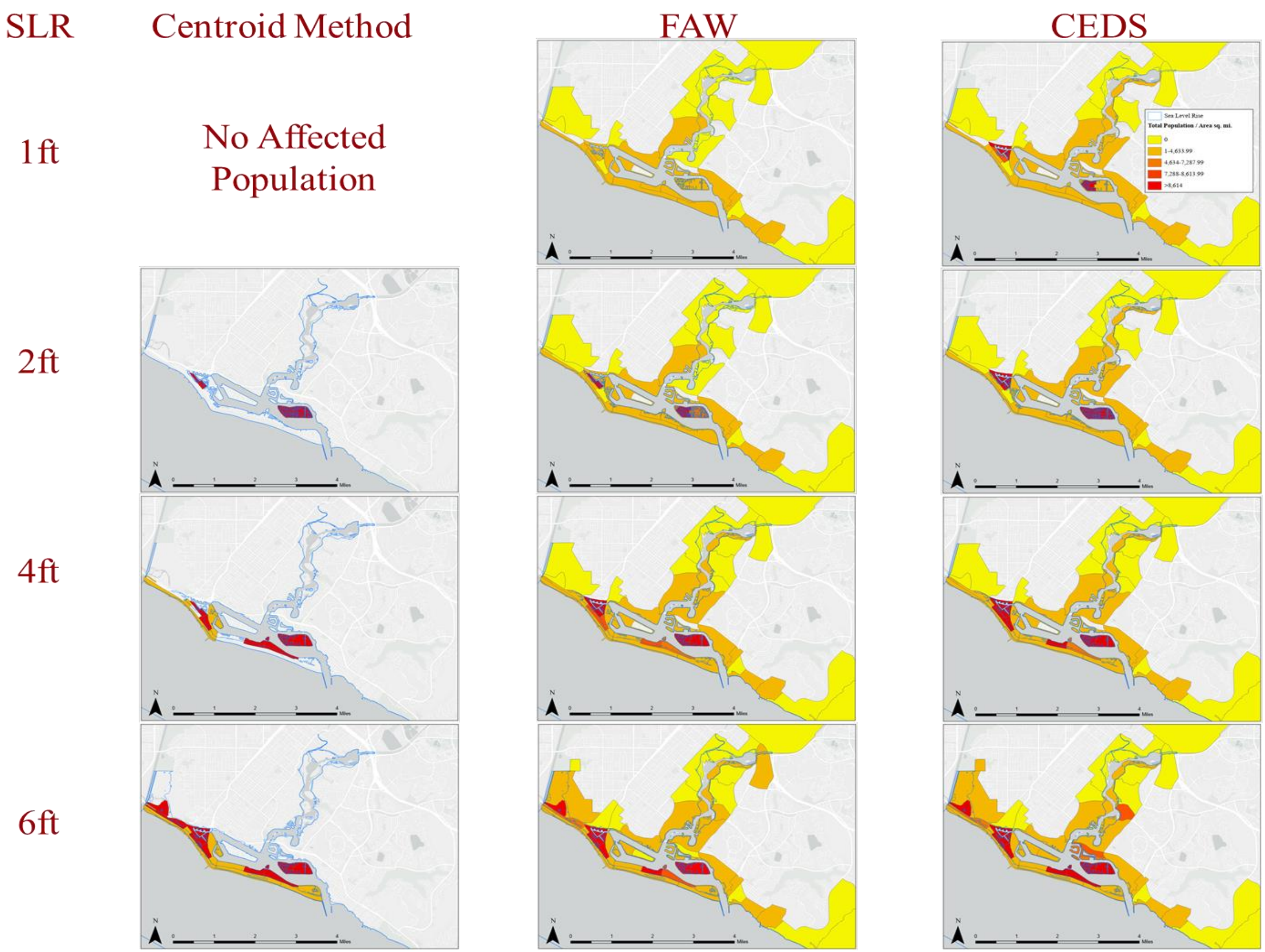

Figure 11: Newport Beach Mapping Methods

The Newport Beach centroid maps are analyzed further with impacts at each inundation, except at the one-foot 2050 GSLR projection because no centroids are inundated. The results of the centroid method workflow in Chapter 3 are shown in Figure 11. Unlike the 2050 GSLR projections, the 2050 RSLR two-foot inundation impacts a large population density at the Balboa Island block groups and one block group that is located at the beginning of the Peninsula and on the Bay. By 2100, the four-foot GSLR projection impacts some of the Newport Shores, the beginning of the Peninsula, and Balboa Island. However, the six-foot RSLR projection impacts all of the Newport Shores, all of the Peninsula, and the Balboa Island. The largest population density impacts in the centroid maps are block groups that touch the bay and towards the Newport Shores. However, this method is not as accurate or precise as the FAW method.

The results of the FAW method workflows in Chapter 3 are shown in Figure 11. Unlike the centroid method, the FAW method contains yellow block groups, which represent zero population densities. For the FAW map inundated by the one-foot 2050 GSLR projection, the block groups that are impacted show no population density impacts. The impacted block groups also portray population density affects within the 1-4633.99 range, shown as the color orange. The orange block groups are located along the coast, which includes the Peninsula, Newport Shores, and Corona del Mar. Balboa Island and some areas directly surrounding Newport Bay also show some impacts. However, within the 2050 two-foot RSLR projection, there are greater impacts to the population density in the Balboa Island and the north-western area of the Newport Bay. Continually, the 2100 four-foot GSLR projection impacts all of the block groups surrounding the entire Newport Bay. Additionally, Balboa Island and the north-western part of the Newport Bay show the greatest population density impacts. Finally, the 2100 six-foot RSLR projection shows the greatest number of impacts to the block groups, with Balboa Island, south of Balboa Island, the north western area of the Newport Bay, and the Newport Shores showing the greatest population density impacts caused by SLR. Even though this method shows more accurate impacts than the centroid method, the CEDS method still provides the most accurate and even the greatest number of impacts to Newport Beach.

Finally, Newport Beach provides the results from the CEDS method, just like in Huntington Beach. The block groups impacted in the CEDS maps match up with the ones in the FAW maps, except the total population impacts show many differences. For instance, the one-foot 2050 GSLR projection shows population density impacts in the 1-4633.99 range to the area south of the ecological reserve. Additionally, the greatest impacts are shown in one block group in Balboa Island and to the north-western area of the Newport Bay. Within the 2050 two-foot RSLR projections, the CEDS map shows the same areas impacted as the one-foot projection, but with greater population density impacts in Balboa Island, and the north-western area of the Newport Bay. By 2100, the four-foot GSLR projections impact more of the north-western area of the Newport Bay, as well as south west of Balboa Island located in the Peninsula. Lastly, the six-foot 2100 RSLR projections show the greatest impacts on the population density located in the Balboa Island, the areas north and south-west of Balboa Island, and one block group shows greater impacts on the population density. Additionally, the areas around North Shores and by the north-western areas of the Newport Bay show even greater impacts than in the four-foot projections. While these maps are described and compared by year and SLR projection type, this project still needs to compare the different mapping methods at each SLR projection.

For Newport Beach, the mapping methods are compared by analyzing both of the 2050 SLR projections. Figure 11 shows that all of the mapping methods in the 2050 one-foot GSLR and two-foot RSLR projections, except for the centroid method at one-foot SLR. Additionally, each mapping method, other than the FAW method affected at one-foot, the block groups with the greatest population impacts are connected to the bay area. The block groups in the centroid method are not connected to the ocean, but the FAW and CEDS methods do have block groups connected to the ocean. For the FAW and CEDS methods, Figure 11 shows the greatest population impacts connecting to the bay and the least population impacts on the north-eastern areas and along the coast. Additionally, the FAW and the CEDS methods have the same number of block groups inundated at one and two-feet, but the CEDS methods show greater population impacts. There are also more block groups in the CEDS methods that have population impacts that don't contain zero than the FAW methods.

Finally, the mapping methods in Newport Beach are analyzed to compare the impacted areas within both of the 2100 SLR projections. In this case, Figure 11 shows all of the mapping methods in the 2100 four-foot GSLR and six-foot RSLR projections that have the greatest population impacts for all of Newport Beach. The block groups in all of the mapping methods are connected to the ocean at the four and six-foot projections. Also, all of the block groups in the FAW and CEDS methods are connected to the ocean on the shoreline of Newport Beach in 2100. Of the impacted block groups in both the CEDS methods, greater population impacts are located in the bay area than the FAW methods. Lastly, some block groups in the CEDS method at six-feet contain zero population impacts, while the similar block groups in the FAW method contain population impacts.

Then, this section continues to analyze each mapping method in the same way as done for Huntington Beach. This section explains the results from the summary statistics in Table 8. The table shows all of the impacts in each mapping technique analyzed for Newport Beach. In section 4.2.1, the results of the impacts on the people in Newport Beach are described for the centroid method by the 2050 and 2100 GSLR and RSLR projections. 4.2.2. describes the similar results found in the FAW method for Newport Beach. Lastly, 4.2.3. describes the results from the CEDS method at each SLR inundation in Huntington Beach.

Table 8: Newport Beach Mapping Method Results

Mapping Method	Sea Level Rise	Total # of Block Groups	Total Population	Total Affected Area (sq. mi.)	# of Block Groups with Population 0	Total Affected Residential Area	# of Hous-ing Units
Centroid-Containment	2ft	3	3,733	0.269	n/a	n/a	n/a
	4ft	7	8,524	0.922	n/a	n/a	n/a
	6ft	13	15,197	1.766	n/a	n/a	n/a
Filtered Areal Weighting	1ft	31	758	n/a	13	0.041	n/a
	2ft	32	3,400	n/a	13	0.149	n/a
	4ft	34	8,430	n/a	13	0.357	n/a
	6ft	38	13,236	n/a	13	0.592	n/a
Cadastral-based Expert Dasymetric System	1ft	31	5,096	n/a	12	n/a	2,543
	2ft	32	8,274	n/a	13	n/a	4,339
	4ft	34	12,476	n/a	13	n/a	6,521
	6ft	38	17,844	n/a	11	n/a	8,587

4.2.1. Further Centroid-Containment Method Results for Newport Beach

Since no summary statistics exist within the one-foot GSLR projection, the Newport Beach centroid maps are analyzed further from impacts created by the 2050 two-foot RSLR projection and the 2100 GSLR and RSLR projections. In Table 8, the results at the two-foot RSLR projection show that a total of three block groups with a total area of 0.269 square miles may be impacted by 2050. From the three block groups, 3,733 of the total population may be impacted. By 2100, the four-foot GLSR projection may impact seven block groups with an area of 0.922 square miles that may be impacted. A total of 8,524 people may also be affected. Within the six-foot RSLR projection, results show possible impacts to a total area of 1.766 square miles in thirteen block groups. From these affected block groups, 15,197 of the total population may be impacted by the regional projection in 2100.

4.2.2. Further Filtered Areal Weighting Method Results for Newport Beach

Furthermore, Table 8 provides the summary statistics of the impacted block groups in each of the Newport Beach FAW maps. As stated earlier, the FAW mapping method produces more accurate results than the centroid method. First, the results from the FAW method intersected at the 2050 one-foot GSLR projection may impact thirty-one block groups with a total residential area of 0.041 square miles. Also, 758 of the total population may be affected, and thirteen of the block groups contain zero population impacts. In fact, of the total affected block groups in each SLR projection, thirteen of them have zero population impacts. Additionally, the results within the 2050 two-foot RSLR projection show that thirty-two block groups may impact a total residential area of 0.149 square miles and 3,400 of the total population. In 2100, however, the results at the four-foot GSLR projection may impact a total of thirty-four block groups with a total residential area of 0.357 square miles. A total population of 8,430 may be affected within these block groups. Furthermore, the results at the six-foot RSLR projection may impact thirty-eight block groups. In these block groups, the entire total residential area of 0.592 square miles may be impacted by the 2100 regional projection. This project also suggests that 13,236 people may be affected.

4.2.3. Further Cadastral-based Expert Dasymetric System Results for Newport Beach

The final summary statistics portion of Newport Beach (Table 8) indicates the results of the CEDS dasymetric mapping within each SLR projection. For instance, the results at the 2050 one-foot GSLR projection may impact thirty-one block groups, with twelve of them containing zero affected population. In those thirty-one block groups, 5,096 of the total population may be impacted by the 2050 global projection. The total number of housing units was discovered in each SLR projection, and the one-foot projection may impact 2,543 housing units in Newport

Beach. On the other hand, the results within the two-foot RSLR projection show thirty-two block groups may portray impacts, with thirteen of them containing zero population impacts. From the block groups, a total of 4,339 housing units, a total population of 8,274, may be impacted in Newport Beach. Furthermore, by 2100, the four-foot GSLR projection shows that thirty-four block groups may contain impacts. Within those thirty-four impacted block groups, 12,476 of the total population may be affected. Similar to the block groups affected within two-feet, thirteen block groups also contain zero population impacts. Additionally, a total of 6,521 housing units may be affected. Lastly, the results within the six-foot RSLR projection provide the largest estimated impacts. In this projection, thirty-eight block groups with a total of 8,587 housing units may be affected by the 2100 regional forecast. Of the affected block groups, eleven of them contain zero population impacts. Also, 17,844 of the total population may also be impacted.

Chapter 5 Discussion and Conclusions

By examining the maps created for Huntington Beach and Newport Beach, it is clear that the SLR phenomenon will create major impacts not just to the population, but the entire coast by 2100. This chapter compares the three different methods performed for both Huntington Beach and Newport Beach. Here, the major results and claims with respect to the three dasymetric mapping techniques discovered in each city are discussed. Then, this chapter describes the limitations of the mapping methods and the data that was used to create the maps in each city. Opportunities for future research are provided in this chapter. The future research investigates other ways major SLR impacts can be mapped and how similar or different can be analyzed to find more impacts. Finally, this chapter concisely summarizes the key contributions of this project to the GIS community, by explaining how people should use this study and how it will help them. To provide this important information, this chapter is split up into three different sections.

The first section in this chapter shows comparisons of the different aspects of the three mapping methods. The next section provides the analysis of the results found in Chapter 4. In section 5.3, the limitations of the mapping methods and the data used in this project are explained. Lastly, section 5.4 provides implications for future research, with some recommendations from other literary works. This section also explains who should look at this study and why they need to examine the work done here.

5.1. Comparison of Methods

When conducting the three mapping methods and processing the necessary data by using ArcGIS Pro, major differences are found based on the various aspects of the methods, as shown in Table 9. This section examines the table to explain how the mapping methods are different and how the mapping methods are different in each city. The workflow of the methods is discussed. Then, the amount of time to complete and edit data manually, as well as the amount of missing data, are discussed to compare the methods in each city.

Table 9: Summary Table of the Three Methods in Huntington Beach and Newport Beach

Mapping Method	Workflow	City	Time	Manual Editing	Missing Data
Centroid-Containment	Polygon to Centroid – census block group ➢ Intersect – centroids with SLR polygons, ➢ Add Join –centroids into block groups	Huntington Beach	10 mins	None	None
		Newport Beach	10 mins	None	None
Filtered Areal Weighting (FAW)	Intersect - residential land use parcels with block group ➢ Dissolve – one land use polygon in each block group, Add Field – total area, Calculate Geometry Attributes – total area of land use ➢ Intersect – land use parcels in block groups with SLR polygons, Dissolve – one land use polygon in each block group, Add Field – impacted area, Calculate Geometry Attributes – total affected area of land use ➢ Add Join – attributes to block group Add Field – 8 new Calculate % of affected residential land use area Calculate total affected population	Huntington Beach	4 hours	About 10% of the land use codes didn't match with the city's land use map	None
		Newport Beach	10 mins	None	None

Mapping Method	Workflow	City	Time	Manual Editing	Missing Data
Cadastral-based Expert Dasymetric System (CEDS)	Intersect – tax lots with block groups ➢ Dissolve – one tax lot polygon in each block group ➢ Intersect – tax lots in block groups with SLR polygons, Dissolve – one tax lot polygon in each block group ➢ Add Join – dissolved datasets into census block groups, ➢ Add Fields Calculate % of number of affected housing units Calculate total affected population	Huntington Beach	2 weeks and 2 days	A lot of the assessor data had to be edited. Made sure assessor data was correct, adding the number of total and impacted housing units	About 10-12% of the assessor data in impact areas
		Newport Beach	1 week and 1 day	Same as Huntington Beach, but not as much	About 5% of the assessor data in impact areas

The centroid method collects the centroids in the census block group that intersect with each SLR projection, as shown in Table 9. This method is the least accurate in the estimation of the impacted population and the affected block groups. Additionally, the SLR may not impact residential areas in the affected block groups, yet the 2018 population data is still collected. However, this method can be useful for a project analyzing population impacts over a large area. For example, if population impacts are analyzed on the U.S. coastline, the project would use this method. Furthermore, out of the three mapping processes, this method is the fastest to perform because no edits are made to the data, and few steps are performed in the workflow.

Next, the FAW method collects the intersected residential land use parcel data and estimates the impacted population from the impacted residential area in each block group. The problem with this method is that it could leave out many residential units. Since FAW only collects the area of the land use parcels, people that live above the first floor of an apartment building may not be included in the analysis. When performing this method in Huntington Beach, it took about four hours to finish because the 2016 residential land use parcels were compared with the land use map provided by Huntington Beach. During this comparison, about ten percent of the land use codes didn't match up, so these were changed to represent the correct land use codes. Because there was not a great deal of manual editing of the land use codes, the analysis is still accurate in Huntington Beach. Alternatively, the Newport Beach land use parcels were not edited in this project because the city's open portal provides accurate land use information, which is updated frequently.

Lastly, CEDS collects the intersected residential land use parcel data joined with the assessor point data when estimating the impacted population. This method is useful for analyzing population impacts on a smaller scale than the centroid method, especially for a coastal city analysis. Since this method relies on the number of housing units or residential units, collecting accurate assessor data is essential to analyze population impacts. While examining the number of housing units in both of the cities, some missing data was discovered in the residential land use parcels. To fix this problem, an extraordinary amount of time was taken to look up the total number of housing units for each residential land use parcel in each of the impacted block groups. This process took about three weeks to complete and involved looking up the addresses, from the assessor data, in Zillow.com and Apartments.com, to find the number of residential units for both cities. For Huntington Beach, the process took about two weeks because there was a lot of block groups affected. Even though there were not as many block groups affected in Newport Beach as there was in Huntington Beach, the process still took about one week to edit the housing units manually. While this step took the longest time, calculating the total number of housing units, percent of housing units impacted, and the number of affected housing units in each block group took about three days to complete. A series of these processes took about two days to do for Huntington Beach, and about one day for Newport Beach. The reason this step took longer than expected was that the Dissolve tool did not allow adding the sum of the housing units, so the calculations had to be performed manually. In the end, these calculations and edits provide this study with a more accurate method, as well as more difficult and more time consuming than the others.

5.2. Analysis of Results

From the creation of the three dasymetric mapping techniques, the population impacts discovered in Huntington Beach and Newport Beach show several key differences and similarities at each SLR projection. Overall, each mapping method projects more people in Huntington Beach to be more susceptible to the SLR than Newport Beach by 2050 and 2100. The projections are greater in Huntington Beach because each SLR projection inundates more land than in Newport Beach. Less land is most likely inundated in Newport Beach because they have created more coastal management projects than in Huntington Beach. In each mapping method, Newport Beach shows less impacted block groups, but with more block groups with zero population impacts than in Huntington Beach. For the city impacts, the population in Huntington Beach is impacted the most in the north-west area of the city, known as the Huntington Harbor. The population is also mostly impacted in the southern area and more inland away from the shore, likely caused by manmade canals. Newport's population, however, is impacted mostly around the Newport Bay and along the shoreline, known as the Peninsula. For each city, the wealthier population may have greater impacts, since the SLR inundations are projected to affect areas close to the shoreline, in harbors, and bay areas. These areas are locations of high property values in each city.

This section further explains the main results found in Huntington Beach and Newport Beach and the differences of each mapping method used for this study. In section 5.2.1., the main population results are shown for Huntington Beach in 2050 and 2100. Section 5.2.2. also provides the population results for 2050 and 2100, but for Newport Beach. By explaining the main population results for each map, each section also discusses the differences of each mapping method to show how the CEDS method is the superior dasymetric mapping method.

5.2.1. Analyzing Population Results for Huntington Beach

By analyzing the maps created for Huntington Beach, the project shows that Huntington Beach has some interesting population numbers at each SLR projection. Huntington Beach has a larger area and higher population numbers than Newport Beach, which is why Huntington Beach has larger overall numbers than Newport beach in each mapping method. The next subsection shows the main results of the total population results for Huntington Beach in each mapping method. This section also provides the differences for each mapping method by looking at the results.

5.2.1.1. Huntington Beach Population Impacts

The total population impacts within each SLR inundation in Huntington Beach show many different impacts than the population density. First, Figure 12 shows that the CEDS method has the largest population impacts within each inundation, just like Maantay and Maroko (2009) stated, should happen. The figure shows that the CEDS method within the one-foot projection has more than 300 people impacted than the centroid method and has more than two times the population impacts than the FAW method. Within two-feet, the CEDS method has about 6,500 more people impacted than the centroid method. The CEDS method also shows about 10,000 more people impacted than the FAW method. Within four feet, the CEDS method has about 12,700 more people impacted than the centroid method. The CEDS method also has about 11,900 more people impacted than the FAW method. Within the four-foot inundation, the FAW method is projected to have more population impacts than the centroid method. Lastly, within six-feet, the CEDS method has about 6,200 more people impacted than the centroid method. The CEDS method also has about 6,800 more people impacted than the FAW method. The CEDS method is projected to impact the population more within the 2050 and 2100 regional projections than within the 2050 and 2100 global projections.

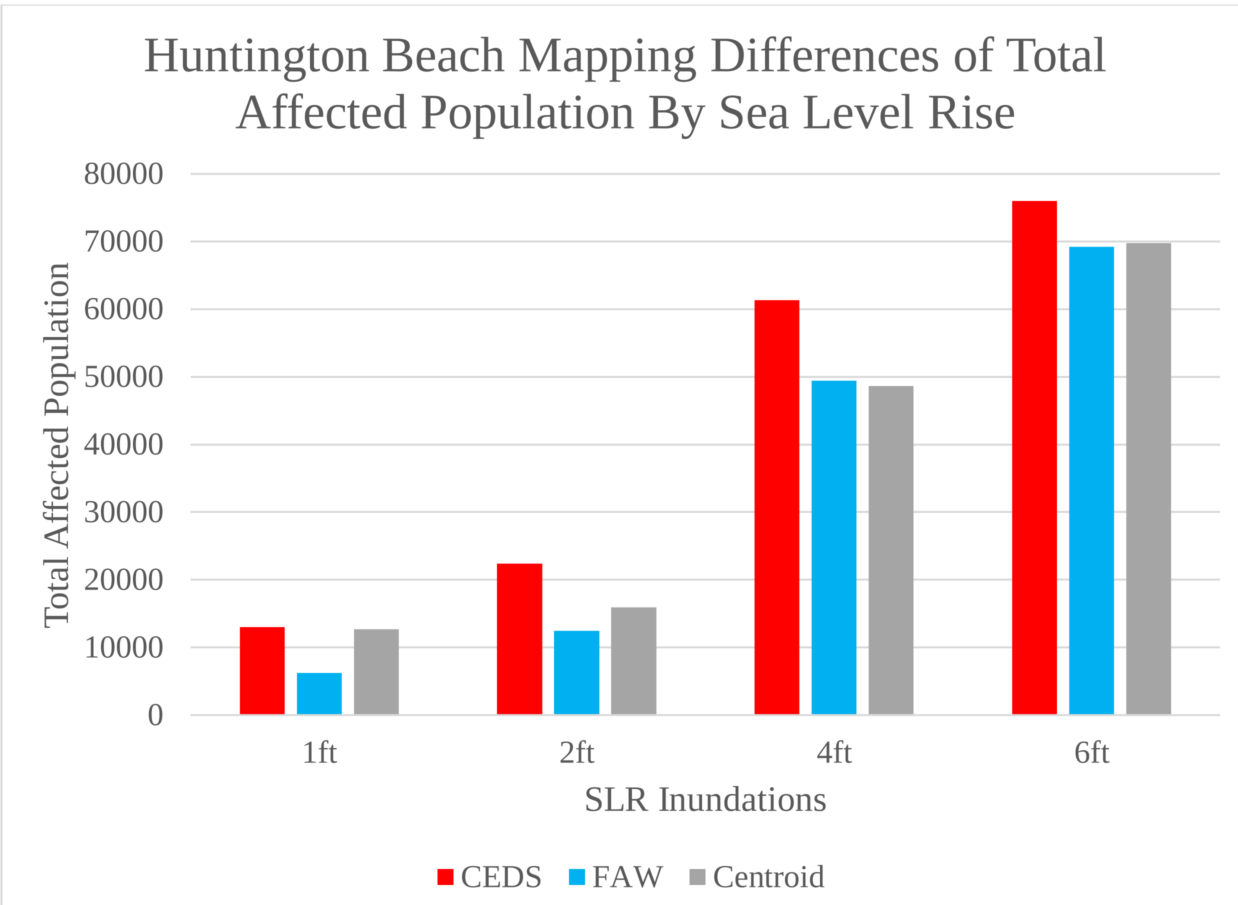

Figure 12: Total Population Impacts in Huntington Beach

Additionally, the analysis of the population impacts in the CEDS method shows some major differences each year within the GSLR and RSLR projections. As shown in Figure 12, the CEDS method shows differences in the population impacts within the projections. Of the

198,724 people in Huntington Beach for 2018, the CEDS method shows that about 6.5 percent of the population may be affected at the 2050 one-foot GSLR projection. However, within the 2050 two-foot RSLR projection, the CEDS method shows that about 11.3 percent of the city's total population may be affected. Between the SLR projections in 2050, there is a 4.8 percent difference. By 2100, the CEDS method shows that 30.9 percent of the population may be affected within the four-foot GSLR projection. While significant impacts on the population are shown within the GSLR projection by 2100 in the CEDS method, there may be 38.2 percent of the total population affected within the six-foot RSLR. Also, there is a 7.3 percent difference between the 2100 SLR projections. By showing the percentage of the total population in the city affected within each SLR projection and year, the main results show larger population impacts within the regional projection. However, it is important to consider all of the possible SLR outcomes in order to better prepare for the future.

5.2.2. Analyzing Population Results for Newport Beach

The analysis of the maps created for Newport Beach shows some interesting population impacts at each SLR projection. The next subsection shows the main total population results for Newport Beach in each mapping method. By explaining the total population results in Newport Beach, this section also provides the differences for each mapping method.

5.2.2.1. Newport Beach Population Impacts

Similar to the population impacts in Huntington Beach, the largest population impacts occur in the CEDS method. Figure 13 shows the total population impacts for each mapping method within each SLR inundation in Newport Beach. After calculating the total population impacts within the one-foot projection, the CEDS method has about 4,300 more people impacted than the FAW method. Within two-feet, the CEDS method has about 4,500 more people impacted than the centroid method, and about 4,800 more people impacted than the FAW method. Within four feet, the CEDS method has about 4,700 more people impacted than the centroid method and about 4,800 more than the FAW method. Lastly, within six-feet, the CEDS method has about 2,600 more impacted people than the centroid method, and about 4,600 more impacts than the FAW. The CEDS method is projected to impact the population more within the 2050 and 2100 regional projections than within the 2050 and 2100 global projections. Also, the centroid method is projected to have more population impacts than the FAW method within each inundation, except at one-foot.

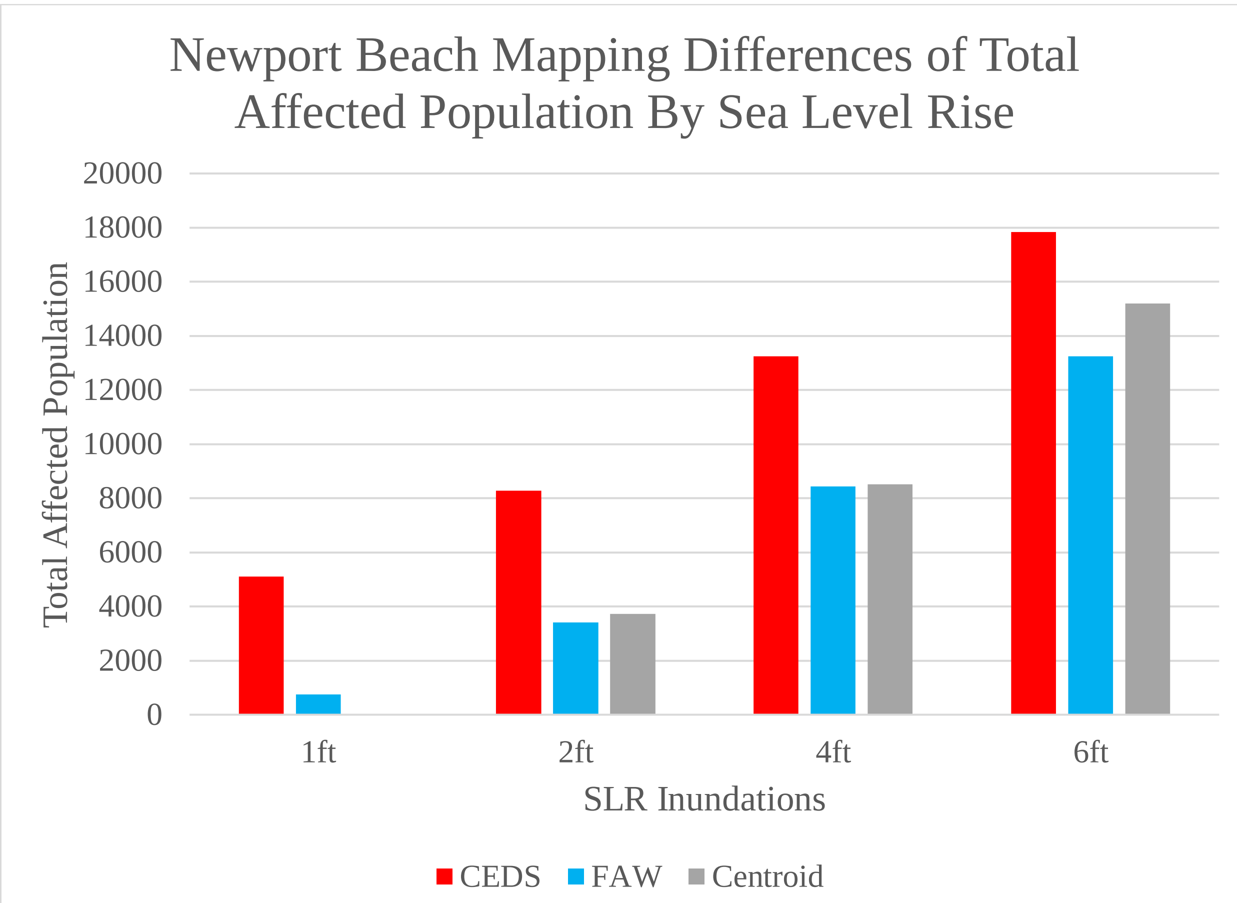

Figure 13: Total Population Impacts in Newport Beach

Even though Newport Beach projects the population impacts to be much less than in Huntington Beach, the CEDS method still shows major differences at each year within the GSLR and RSLR projections. As shown in Figure 13, the population impacted within the 2050 GSLR one-foot projection about 5.9 percent of Newport's 86,813 population in 2018. Within the 2050 two-foot RSLR projection, about 9.5 percent of Newport's total population may be affected. For the 2050 projections, there is about a 3.6 difference between the two 2050 SLR projections. Additionally, the CEDS method shows that the population impacted within the 2100 four-foot GSLR projections maybe about 15.2 of Newport's total population in 2018. However, within the 2100 six-foot RSLR projection, about 20.6 percent of Newport's total population in 2018 may be impacted. Between the 2100 RSLR and GSLR projection, there is a 5.4 percent difference. These total population impacts in Newport Beach, not only show the difference between each SLR projection, but they also show how they are different at each year.

5.3. Study Limitations

While this study did use the spatial datasets to create the three mapping methods correctly, there were still some limitations that this project uncovered along the way. This study came across some limitations with the datasets that were used to make the mapping methods. In the first section, the limitations of the census data are described. The next section describes the limitations of the SCAG land use parcels for Huntington Beach. Next, the limitations and problems that arose while using the assessor data is described. Lastly, the limitations of the SLR datasets, downloaded from NOAA, are described.

5.3.1. Demographic Data

The census data had some limitations in this project, especially with the 2018 population totals in Huntington Beach and Newport Beach. For instance, the population totals that were analyzed in this project were in 2018. The analysis could be improved by using demographic models that predict future population states. This could work with the CEDS model by accurately predicting where people may be impacted the most and how those areas may change over time. Also, some of the block groups located in Huntington Beach and Newport Beach overlap outside of the city boundaries. By overlapping outside of the city boundaries, the area and population totals account for other cities as well. Fortunately, there weren't a significant number of block groups that were impacted that overlap outside the city boundaries to affect the data largely.

5.3.2. Land Use Data

Another limitation with the data used in this project, was with the residential land use data used for Huntington Beach. Since SCAG only has the 2016 land use classifications, some of the land uses in Huntington Beach were incorrect, or used the general plan classifications. For instance, some of the roads and the borders of the residential areas were classified as residential areas. They were switched to open areas to account for the 2016 land uses. Also, some of the areas that had assessor points in them were classified as open areas, so those parcels were switched to residential land uses. This step was taken, so when the intersect step was done for the FAW mapping method, all of the residential land uses in that block group would be accounted for. If the land use parcels were more accurate, the total area and the percentage of impacted areas would be more accurate. Some of these land-use parcels that didn't have a residential land use classification had a lot of housing units in them because the assessor points had 2017 data, and the land use parcels had 2016 data.

5.3.3. Problems and Limitations with Assessor Data

The next dataset that had some major limitations in this study was the assessor data, from Boundary Solutions. First, the assessor data that was used in this project was vector point data because Boundary Solutions didn't have all of the parcels with the essential attributes for both cities. If Boundary Solutions had all of the parcels in them, analyzing the number of housing units could have been much more accurate and less time-consuming. Also, the attributes in the dataset were created for the year 2017. Because these attributes were created in 2017, some of the points had different land-use classifications than the 2016 Huntington Beach and 2020 Newport Beach land use parcels. If the land uses were in the same year, then the accuracy of the total impacted number of housing units could have been better for each city. Not only were their limitations to the assessor data, there were also problems that occurred when utilizing the assessor points for the mapping methods.

The main problem working with the assessor data occurred during the data preparation workflow. Some of the land use parcels contained multiple points in one parcel. Multiple points in the parcels created a problem because this project couldn't perform a one-to-one spatial join to show the total number of housing units in that parcel. This project had to perform a one-to-many spatial join to account for all of the points in the parcel. This step created a problem because there were many of the same land use parcels, but with different assessor point attributes. From here, the project had to count the number of housing units for each of the parcels and then delete the excess parcels once finished. This step took the most amount of time and created the most amount of problems. The reason that this step was performed was that this residential land use data was used for the FAW method and the CEDS method in both Huntington Beach and Newport Beach. As explained here, the assessor point data created the most problems and limitations while creating the mapping methods.

5.3.4. Sea Level Rise Data Accuracy

Lastly, this project also came across a limitation from the SLR datasets downloaded from NOAA. The main limitation that this project came across was explained in Chapter 2. The SLR polygons weren't exact projections that the IPCC (2019) and the Committee (2012) gave for their projections by year, but they were close. If NOAA provided more precise SLR projections, the number of total populations impacted in each city could have been more accurate by year. Also, the total number of people impacted by SLR would be less than what this project predicted.

5.4. Recommendations for Future Research

Other than mapping the total population impacts, this study provides several suggestions on how to analyze other impacts caused by SLR. Expanding the project would help provide more research into how to map SLR impacts and the other important spatial data that should be analyzed. The first section explains how economic impacts can be analyzed by examining past research. In 5.4.2, the environmental impacts caused by SLR is another important aspect that can be helpful to expand this research project. Also, the third section explains how other population impacts should be analyzed beyond just focusing on the total affected population. Lastly, this project explains how this study can be used in the same or different, coastal cities. This section also provides information on how certain government agencies than use this study for their own use.

5.4.1. Analyze Economic Impacts

Since there is a lot of economic development on the coast, one future research recommendation is to analyze the economic impacts that SLR may impact on Huntington Beach and Newport Beach in the future. As mentioned before, in Chapter 2, Huntington Beach has a lot of tourist amenities, which include many upscale hotels, restaurants, and retail stores. Huntington Beach also provides numerous housing developments and other businesses that generate a lot of money for the city. Newport Beach also has numerous housing developments and businesses within the SLR projected impact areas, but at a much higher property value than Huntington

Beach. These are a few potential ways that these economic developments can be spatially analyzed with GIS technology to show the impacts of SLR.

One way that these economic developments can be analyzed is through the Felsenstein and Lichter's (2013) process. As explained in Chapter 2, they used Moran's I statistics to show the economic vulnerability off coastal communities. Then they made a 3D model showing the socioeconomic impacts that the SLR projections may affect. The article included the occupation, education, ethnicity, age, and marital status at the tract level, for the socioeconomic data. Instead of performing this analysis in Tel Aviv, a project using this framework could help analyze the economic impacts in Huntington Beach and Newport Beach. Also, instead of using the tract level, like Felsenstein and Lichter (2013), an analysis could be more helpful at the block group level for each city. This analysis would help spatially analyze the socioeconomic impacts and the housing impacts in coastal areas.

Another way, and more effective than Felsenstein and Lichter (2013), is to analyze economic development using Maantay, Maroko, and Herrmann's (2007) CEDS method. This type of project would have to show how the residential units in Huntington Beach and Newport Beach may be impacted based on the number of housing units, as well as their total property values at different SLR projections. The CEDS method would be created and analyzed the same way as in this project while finding how much the economic impact would be based on their total property value. Then each block group could show the number of housing units impacted and the total value that each SLR projection would impact up to 2100. With this type of project, the assessor data for the property values have to have the most up to date and accurate property values in the assessor data points.

Furthermore, not only can a future project analyze the economic impacts of residential units in Huntington Beach and Newport Beach, but a project can use GIS technology to show the economic impacts of the businesses as well. Since the Business Analyst point data is not very accurate or precise, a researcher could go out with a GPS device to provide accuracy to the location of the business and receive business information from the businesses as well. Then a project could create CEDS maps of the business and housing impacts within the different SLR projections. The business impacts could show the number of sales, or income, produced per year, as well as the total property value of the business. This project would take the most amount of time, but it would provide a complete economic analysis for each city up to 2100.

5.4.2. Analyze Environmental Impacts

As mentioned before, in Chapter 2, future SLR could cause the environment to have some serious impacts, especially in Huntington Beach and Newport Beach. Chapter 1 pointed out that these two cities provide diverse wildlife along their coasts, especially in their large coastal wetlands. In Huntington Beach, The California Department of Fish and Wildlife (2020) states that the 1,300-acre Bolsa Chica Ecological Reserve is a coastal estuary home to over 200 different avian species, over sixty different species of fish, as well as several rare and endangered plants. While the Huntington Beach estuary is larger, the Newport Bay Conservancy (2020a) describes the 752-acre Upper Newport Bay Ecological Reserve to be the jewel of Orange County’s coast. This estuary is home to nearly 200 avian species, including four different endangered species (Newport Bay Conservancy 2020b). Also, the conservation area is home to many mammals, including the bobcat being the largest. With all of this information on these coastal estuaries, future projects are necessary to analyze the environmental impacts caused by SLR in each city.

One way to create a project to study environmental impacts caused by SLR is to replicate Schmid, Hadley, and Waters's (2014) novel process for Huntington Beach and Newport Beach, briefly explained in Chapter 2. Their project, for Charleston, South Carolina, was about how to spatially analyze and utilize different tools to find the SLR inundation uncertainty. In the article's previous work section, the author explains the Sea Level Affecting Marshes Model is a type of single-surface sea-level mapping model that incorporates local geomorphic and groundwater parameters to highlight areas of potential habitat change. This model could help provide an analysis for Huntington Beach and Newport Beach to show how the habitats may change within the different SLR projections.

5.4.3. Expand the Population Analysis

Not only can the SLR impacts of the total population be analyzed, but the socio-economic attributes of the total population should be analyzed to provide more information on what types of people might get affected by SLR. Analyzing the socioeconomic attributes of the population is important so that government agencies know where to help the people most in need and where they should build coastal management projects to protect those people. This analysis could benefit most, if not all coastal communities projected to have impacts from future SLR.

Maantay and Maroko (2009) mentions that future CEDS maps need to extend beyond the total population impacts caused by SLR. Their article states that using socioeconomic data, such as age, race, and income, would further the creation of the CEDS map, as well as further the analysis of population impacts caused by SLR. By creating a CEDS map that shows the socioeconomic status of the population affected by SLR, the map could potentially help people over the age of sixty-five, and the non-white population. This map would also be able to help the people that have an income at or below the poverty line. The government would be able to provide help faster and more accurately if these people are affected. Therefore, creating a more in-depth CEDS map is crucial to the safety of the city's population.

5.4.4. Potential Uses of Work

By creating three different dasymetric mapping methods and analyzing the population impacts caused by the global and regional SLR projections in two different Southern California cities, several potential uses can provide help to different authorities around the world. The information about the workflow of the CEDS method can be important for geospatial experts. The authorities include local governments on the west and east coast of the U.S., as well as the federal government, and government agencies. Additionally, this project can provide help to other coastal areas around the world, not just in the U.S. While this study can provide important information to governments and government agencies, GIS professionals and scholars could benefit from looking at this study. Furthermore, large corporations that focus on energy consumption could also benefit from a review of this project.

Even though large energy corporations, like Royal Dutch Shell and Exxon Mobile, generate billions of dollars a year, this study can show why it is important for these corporations to make more environmentally conscious decisions. These environmentally conscious decisions can include reverting to more renewable energy practices. These corporations can even help coastal cities with coastal management projects since they cost a lot of money. If these corporations make more of these decisions, they could help decrease both of the potential GSLR and RSLR rates around the world. As a benefit of being more environmentally conscious, these corporations may be able to generate more money by gaining trust in the community. In fact, a non-profit, called Carbon Disclosure Product Worldwide, shows how corporations can secure a higher return on investment if they are actively managing and planning for climate change

(Confino 2014). Additionally, the energy corporations that manage and plan for climate change can secure an even higher return on investment if they disclose their emissions than the ones who refuse (Confino 2014).

Since this project provides the CEDS mapping workflow and results, as well as analyzing impacts within all of the possible SLR projections, different types of agencies can use this information to possibly add on to their SLR models and create more accurate impact analyses. While agencies that deal with climate change can create a more accurate SLR impact analysis with CEDS, other agencies can use the same method to map out other phenomena impacts. The phenomena could include natural disasters, like earthquakes, or even the impacts on the population caused by pandemic diseases, like COVID-19 in 2020. Additionally, a number of different government and protection agencies can use this project. Some of the main agencies that deal with climate change would include the USGS, The Federal Emergency Management Agency (FEMA), NOAA, and the California Ocean Protection Council. Additionally, some protection like agencies could include the Red Cross, and even the Center for Disease Control.

Furthermore, this project can be helpful to the federal government in the U.S. Not only can the CEDS maps created for this project show the federal government where the two cities would need a coastal management project, but the federal government could also help provide loans to other U.S. coastal communities. The information about the global and regional SLR projections is also helpful to the federal government because, hopefully, they would have enough information to make more environmentally conscious decisions. Making more environmentally conscious decisions can create solutions to decrease the amount of GHG emissions. As mentioned in Chapter 2, GHG emissions are a major factor in causing SLR. So, by decreasing the amount of GHG emissions in the atmosphere, the global and regional SLR projections would decrease as well. Similar to the energy corporations, the federal government could possibly gain more approval from the people by choosing to be more environmentally conscious.

Not only does this project provide an accurate population impact analysis to the federal government, but the local governments of the U.S. cities on the west and east coast can use this project's framework to analyze their possible population impacts more accurately. While west coast cities that are not located south of Los Angeles cannot use this project's 2050 and 2100 RSLR projections, they can follow the CEDS workflow to project population impacts intersected within the 2050 and 2100 GSLR inundations. These west coast cities can also look at the other RSLR projections that the Committee (2012) provides in their article. However, the east coast cities have much different GSLR and RSLR projections than the west coast cities. Nevertheless, both the west coast cities that are north of Los Angeles and the east coast cities can follow this project's CEDS mapping workflow to analyze population impacts caused by SLR more accurately. The IPCC (2019), which is given in this project, also provides the other west coast and east coast GSLR projections. Also, these coastal cities are able to find the number of housing units and residential area impacts more accurately by following the CEDS workflow.

Moreover, this study is able to provide the most insight for the local governments of Huntington Beach and Newport Beach, through the use of the generated maps within the 2050 and 2100 global and regional SLR projections. Particularly, the CEDS maps created for 2050 and 2100 provide the cities with the most accurate total affected population within each of the global and regional SLR projections. Additionally, these maps also show a more accurate visual representation and analysis of where people may be most vulnerable. Hence, the cities know where to send help faster with more accuracy. By explaining the workflows of the FAW and CEDS methods, the cities can apply their own up to date and more accurate census, land use, and assessor data for better accuracy and precision. Applying these new datasets can potentially show more accurate impacts on the population, the number of housing units within the land use parcels, and the residential area that are within the 2050 and 2100 SLR projections. By considering information provided by this study, the cities can plan development projects with more accuracy and awareness of future potential SLR. The CEDS maps can also help the cities make better decisions about the locations and types of future coastal management projects that should be created. Coastal management projects are very expensive, even for cities like Newport Beach, but they are necessary to help prevent or slow down the rate of SLR.

Finally, geospatial experts can use the workflow for the CEDS method to advise officials numerous aspects of SLR impacts and planning processes in coastal areas. By following the CEDS workflow, geospatial experts can provide local governments with more precise maps about how SLR may impact their population over time and space. These experts can then advise the officials on how to allocate funding for local governments to handle the managed retreat from the coastline. The experts can also use this information to provide the jurisdictions with the most significant number of people being impacted. After factoring in different socioeconomic elements, like age, race, and income, they can provide the local officials with the areas that could be more susceptible to future SLR.

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