City of Santa Barbara Sea Level Rise Vulnerability Assessment

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Declaration of Authorship

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

James Frew, PhD

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Abstract

The coastal areas of California are some of the most highly developed parts of the state. Coastlines will be significantly impacted by climate change in the coming decades by processes such as sea level rise. Consequences of sea level rise include permanent inundation, wave damage, and bluff erosion. The City of Santa Barbara (the City) is addressing these previously mentioned hazards within an update of the City's Local Coastal Program (LCP), which guides planning and policy within the Coastal Zone. This study identifies where Santa Barbara is vulnerable to sea level rise related hazards within human populations, critical infrastructure, recreation and public access, as well as ecological resources. Adaptation strategies are identified in this report that the City can consider for their LCP update. These strategies can help the City create a more resilient community in the face of sea level rise related hazards.

Executive Summary

Over the next few centuries, sea levels in California are expected to rise at accelerating rates due to climate change, causing increases in storm surge and erosion-related hazards (NRC, 2012). As a result, the Santa Barbara coastline will face more frequent flooding and bluff erosion, two of the area's historic vulnerabilities (Russell & Griggs, 2012).

The City of Santa Barbara (the City) is working to plan for these anticipated changes, and in order to do so they must better understand the current and future risks to its resources and populations. This report serves as a vulnerability assessment to inform the City of these hazards for an update to the Land Use Plan of their Local Coastal Program (LCP) and to precisely assess coastal vulnerabilities to help identify appropriate adaptation measures.

Exposure Modeling

Exposures to permanent inundation, storm surge, and bluff erosion were modeled in order to assess their impacts on Santa Barbara.

Permanent Inundation Modeling

A modified bathtub inundation model was created, using LiDAR (Light Detection and Ranging) elevation data from 2010, to analyze the effects of different amounts of sea level rise in Santa Barbara. This assessment modeled nine different values of sea level rise taken from the National Research Council (NRC)'s sea level rise report (NRC, 2012).

Storm Surge Modeling

FEMA (Federal Emergency Management Agency)'s modeled Base Flood Elevations (BFEs) of a 100-year storm were added to the sea level rise scenarios to assess storm surge exposure, which adds approximately 11 feet onto each scenario.

Bluff Erosion Modeling

Finally, bluff erosion hazards were modeled using average erosion rates for Santa Barbara bluffs over a time horizon of 75 years, used by the City as the planned lifetime of a building or structure.

Human Populations Sensitivity

Human populations were analyzed in American Community Survey (U.S. Census Bureau, 2013) block groups. Populations within the Coastal Zone are low sensitivity, due their low population density overall and lack of attributes that have been identified to cause a population to be sensitive to sea level rise, such as renting or not having access to a motor vehicle. Some high and medium sensitivity block groups may be affected during a 100-year storm surge. Bluff erosion will affect populations on the Mesa, Braemar, and Clark Estate, which are considered to have a low sensitivity overall.

Critical Infrastructure Sensitivity

Santa Barbara's coastline includes a significant amount of critical infrastructure. Transportation systems such as roads and the railroad will be affected by inundation eventually and by a 100-year storm surge today. Structures are more likely to be affected by storm surge than by permanent inundation, which is relevant to future planning efforts for the City.

Recreation and Public Access Sensitivity

Most of Santa Barbara's recreation and public access sites are along the coastline and within the downtown area. Many of these are highly developed, making them particularly sensitive. The City's major beaches, the Harbor, and Stearns Wharf were identified as the most sensitive assets. In addition to being highly sensitive, these sites were also identified as the most exposed, making them some of the most vulnerable assets overall.

Ecological Resources Sensitivity

All ecological resources within the coastal area of Santa Barbara are important habitats for federally listed species. Based on this analysis, Santa Barbara's coast includes high and medium sensitivity ecological resources.

Adaptive Capacity

Multiple adaptation strategies are offered to the City for consideration, broken down by each element of analysis. Given its monetary and time constraints, the City can identify which adaptation strategies are most effective given the predicted impacts that will be felt on the City. The primary adaptation options for sea level rise include fortifying structures, armoring coastlines, and relocating away from coastlines. Within these categories, there are multiple strategies that the City can consider in their sea level rise policy implementation.

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1.1 Project Significance

Over the next few centuries, sea levels in California are expected to rise at accelerating rates due to climate change, causing increases in storm surge and erosion-related hazards (NRC, 2012). As a result, the Santa Barbara coastline will face more frequent flooding and bluff erosion, two of the area's historic vulnerabilities (Russell & Griggs, 2012). The City of Santa Barbara (the City) is planning for these anticipated changes. To do so they must understand the current and future risks to Santa Barbara's resources and populations by performing vulnerability assessments.

This Sea Level Rise Vulnerability Assessment report provides the City with scientific insights into the physical, social, economic, and ecological aspects of sea level rise. The report will both inform the City's update to the Land Use Plan of their Local Coastal Program (LCP), and help the City identify and prioritize appropriate adaptation measures.

Every coastal city within California is required to have an LCP certified by the California Coastal Commission (CCC) pursuant to the California Coastal Act of 1976. According to CCC directives, LCP updates should address climate change hazards, including sea level rise. As such, sea level rise is now identified as a hazard to address in LCP updates. To encourage this planning focus, the CCC provides grants to support updates to LCP's that include an aspect of sea level rise planning.

In 2014, the City received a grant from the CCC to update their LCP, which includes a Land Use Plan as well as an Implementation Plan. The City intends to include adaptation policies to address sea level rise related hazards. With a better understanding of the coastal processes involved in sea level rise and how these hazards may translate into real losses for Santa Barbara, the City will be able to better uphold the Coastal Act's goal to, "Protect, maintain, and where feasible, enhance and restore the overall quality of the Coastal Zone environment and its natural and artificial resources" into the future (CCA, 1976, §30001.5).

1.2 Project Objectives

In order to inform the LCP update, this Sea Level Rise Vulnerability Assessment report addresses the impacts of sea level rise with respect to the following four elements of analysis, as recommended by the CCC's Draft Sea-Level Rise Policy Guidance (2013):

- Critical Infrastructure
- Human Populations
- Recreation and Public Access
- Ecological Resources

A sea level rise vulnerability assessment was conducted, analyzing the effects of inundation, storm surge, and erosion on the City. The scope of this project includes the contiguous Coastal

Zone of the City of Santa Barbara and all areas at risk from projected future coastal hazards. (The Santa Barbara Municipal Airport is excluded from this analysis as it is certified by a separate LCP, and has conducted its own vulnerability study).

Specific goals of this project are to:

1. Conduct a detailed vulnerability assessment to assess the impacts of sea level rise hazards on human populations, critical infrastructure, recreation and public access, and ecological resources, by expanding upon and updating the existing Sea Level Rise Vulnerability Study (Griggs & Russell, 2012).
2. Prepare a comprehensive Sea Level Rise Vulnerability Assessment report detailing the methods and results of our analyses.
3. Identify preliminary adaptation policies that address the impacts of sea level rise, storm surge, and erosion on Santa Barbara's coastal population, to incorporate into the Land Use Plan update and Implementation Plan.
4. Assemble and organize all data and methods used in this study into a package for the City.
5. Present the findings regarding sea level rise hazards and projected impacts to the City and LCP update committee.

The Sea Level Rise Vulnerability Assessment report will be delivered to the City in compliance with deadlines for the Bren School Master of Environmental Science and Management (MESM) requirements. This report includes:

- Updated storm, inundation, and erosion hazard maps
- Vulnerability assessments for human populations, critical infrastructure, recreation and public access, and ecological resources
- Adaptation options for coastal assets

A data and methods package will be delivered to the City in spring of 2015. Additionally, a Communications Strategy for public awareness and involvement will be delivered to the City in June of 2015 as a separate document.

The County of Santa Barbara Coastal Resiliency Project, funded by a California Coastal Conservancy Climate Ready grant, has been working to model sea level rise, wave runup, and erosion hazards for all of Santa Barbara County. Although the timeline of the County's project extends beyond this group project's delivery date, part of our report's objectives is creating a reproducible framework to easily incorporate new scientific data. Due to conflicting project schedules, this group project report was not able to include data from the County's study within this assessment. For a preliminary comparison of the County's data with the results of this group project, please see **Appendix G**.

1.3 Report Structure

The rest of this group project report includes:

- An introduction to the most relevant topics for understanding a sea level rise vulnerability assessment (**Chapter 2**)
- A description of assessment methods (**Chapter 3**)
- A chapter describing results as relevant to the four elements of analysis (**Chapter 4**)
- A discussion of adaptive capacity and assessment limitations (**Chapter 5**)
- A conclusion summarizing key facts and results of the assessment (**Chapter 6**)

2. Introduction

The City of Santa Barbara is home to a population of more than 90,000 individuals (U.S. Census Bureau, 2013). It has a Mediterranean climate, wide, sandy beaches, and shoreline bluffs. The scenic coastline of Santa Barbara contributes to the economic prosperity of the region due to the volume of tourism that it attracts. Santa Barbara's coastline has played an important role in the growth of the city and is a focal point of the community.

Development of the Santa Barbara coastline began in the 1870s with the construction of Stearns Wharf, which made the City easily accessible by commercial boats (Graham, Bauman, Dodd, Geraci, & Brel Murray, 1994). In 1929, a breakwater was built, enabling the development of Santa Barbara Harbor. Stearns Wharf and the Harbor serve as important commercial and recreational centers today. Santa Barbara's coastline is a highly developed area, which makes the city vulnerable to coastal hazards like sea level rise. Resources along the coast include residential, commercial, recreational, and open space areas. The Santa Barbara Channel is known for being a biodiversity hot spot and is revered for its natural beauty, which is one of the primary drivers of Santa Barbara's large tourist and recreation economy.

2.1 Sea Level Change

Santa Barbara's natural coastal environment is a diverse mixture of low-lying wetlands, steep coastal bluffs, creeks, lagoons, and beaches. The unique bluff topography is characteristic of a historical marine terrace. This is indicative of a historical drop in sea level, which leaves former beaches as long, flat shelf areas on top of steep bluffs or cliffs (Gurrola, et al., 2014). The Santa Barbara Channel is known for being a biodiversity hot spot and is revered for its natural beauty, a primary driver of Santa Barbara's large tourist and recreation economy.

2.1.1 Global Sea Level Rise

Average sea levels have been rising globally since the last glacial period, approximately 15,000 years ago. However, the rate of increase has accelerated dramatically in the last hundred years–from around 0.25 mm per year to nearly 2 mm per year (NRC, 2012) and has been correlated with a rise in average atmospheric temperatures globally (Vermeer & Rahmstorf, 2009). As global temperatures rise, glaciers on the land begin to melt, which contributes to increases in sea level. Furthermore, the rise in global temperatures also causes thermal expansion of the ocean (NRC, 2012). Both of these effects from warming constitute eustatic or volume related changes in sea level (Gregory et al., 2013).

2.1.2 Local Sea Level Rise

Isostatic changes in sea level incorporate the movement of landmasses into the amount of rise observed in an area (Gregory et al., 2013). For example, melting land ice from Alaska and Greenland cause relative sea level to fall in southern California because of a relief in the gravitational forces on the continent overall.This causes the continent to be lighter and rise over time. The combination of the movement of land formations globally has reduced the relative amount of eustatic sea level rise in Santa Barbara by about 14% from 1992-2008 (NRC, 2012). However, Santa Barbara's downtown area is also subsiding at a roughly linear rate of 1-2 mm per year–intensifying the effects of even small changes in sea level (Keller, 2011).

Santa Barbara's tide gauge, located on the City Pier, offers limited information on local sea level rise due to its short measurement history: only 17 years of data (the tide gauge has been in Santa Barbara for more than 17 years, but the instrument was turned off during reconstruction of the wharf as well as during an El Niño storm when it was damaged). Sea level trends for the Santa Barbara tide gauge can be seen in **Figure 2.1**. While it seems that the local sea level may be slowly rising, this trend may partially be due to the combined effects of storm activity and elevated tides during an El Niño Southern Oscillation (ENSO) event. (Griggs & Russell, 2012)

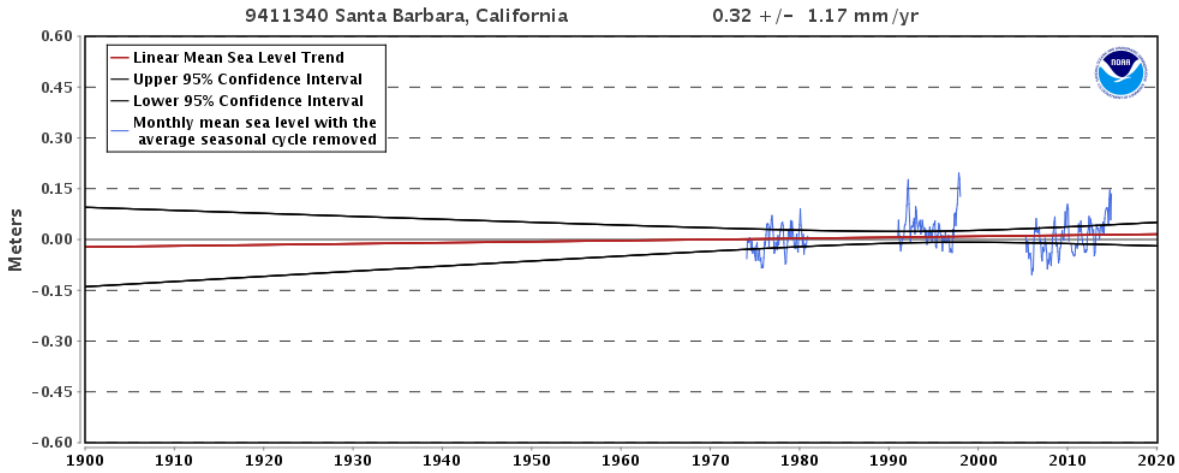


Figure 2.1: Sea level trends at Santa Barbara Harbor tide gauge.

Future Predictions of Sea Level Rise

The multiple variables affecting sea level rise make future sea levels very hard to predict. Sea level rise models, including the Intergovernmental Panel on Climate Change (IPCC) models, generally project to the year 2100. The National Research Council (NRC) downscaled and modified the IPCC's Fourth Assessment Report to project local sea level rise projections for various locations along the coasts of Washington, Oregon, and California (NRC, 2012). See **Table 2.1** for the range of projections estimated for the Los Angeles area, relative to the year 2000. For more information regarding NRC projections and the IPCC scenarios used, refer to **Appendix B**.

Table 2.1: National Research Council sea level rise projections for Los Angeles, California (NRC 2012).

Time Period	Sea Level Rise (in)	Sea Level Rise (m)
2000 - 2030	1.8 - 11.8	0.05 - 0.30
2000 - 2050	5.0 - 23.9	0.13 - 0.61
2000 - 2100	17.4 - 65.6	0.44 - 1.67

2.2 The Effects of Storms

Perhaps the most substantial and damaging impact of elevated sea levels is the resulting increase in coastal storm damage. While sea level rise is a gradual process, coastal storms

are unpredictable and can cause temporary sea levels that are much higher than ambient sea levels. The two main components of coastal storm damage are storm surge and wave runup. Sea levels can also rise during El Niño years for up to months at a time.

Another important threat to coastal communities is tsunami waves resulting from offshore earthquakes or landslides. Since these are sporadic and unpredictable, they are not included in this group project analysis.

2.2.1 Storm Surge

Storm surge is the rise of water generated by a storm over and above normal tides and is caused by wind and low pressure of a storm event that pushes water on shore. Factors affecting the amount of storm surge include the intensity and speed of the wave, as well as the specific features of the coastline (NOAA, 2014). Storm surge, coupled with wave power and wind produced by the storm, can be a destructive force to coastlines.

Climate-driven increases in ocean temperatures are predicted to increase the frequency and intensity of extreme storm surge events (Heberger, et al., 2009). Models predict that in future decades, California will continue to be affected by coastal floods from storm surge (Cayan et al., 2009; Neiman et al., 2008).

2.2.2 Wave Runup

Wave runup is the vertical movement of the waves onto the beach or bluff. This process can cause major damage on the coast because of the destructive power of waves and the debris carried by them. A storm in March 2014 illustrated the power of wave damage when a wave crashed through windows of Moby Dick restaurant on Stearns Wharf. **Figure 2.2** shows wave runup on the breakwater from a high wave event in August, 2014 caused by a distant storm.

Figure 2.2: Wave runup event at the Santa Barbara Breakwater in August, 2014.

2.2.3 Flooding

An important result of a combination of storm surge and wave runup is coastal flooding. One of the primary areas affected by storm surge and wave runup are areas with large floodplains. A floodplain is a low-lying, relatively flat area that adjoins inland and coastal waters (National Research Council, 2009). The term 100-year flood refers to a flood that has a 1 in 100 (or 1%) chance of occurring in a given year ("National Weather Service Glossary", 2009). The Federal Emergency Management Agency (FEMA) designates 100-year floodplains; there often include building code restrictions to decrease impacts from flooding.

Santa Barbara experienced extreme flooding events in 1862, 1914, 1983, and 1995 (Griggs & Russell, 2012). The current coastal areas that experience flooding during high tides and storms are Mission Creek, Laguna Channel, Sycamore Creek, and Arroyo Burro Creek (Griggs & Russell, 2012).

Precipitation and floods within rivers exacerbate flooding events from large storms, but they are not associated with increases in sea level rise, so they are not included in this group project analysis.

2.2.4 El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) is a short-term (multi-year) variation in regional climate that has a profound impact on coastal storm damages. ENSO conditions vary between a warmer climate phase and a colder climate phase. These are termed El Niño and La Niña, respectively, and vary in length between two and seven years. ENSO events occur from a shift in the structure of the equatorial Pacific thermocline and the strength of the easterly trade winds resulting in changes in weather patterns like rainfall (Collins et al., 2010). During the El Niño phase, sea levels along the eastern Pacific coastline often rise 20 cm due to both a relieved forcing from equatorial winds and thermal expansion of the ocean due to warmer sea surface temperatures, and can remain elevated for months at a time (Bromirski, Flick, & Cayan, 2003; Bromirski & Flick, 2008). El Niño phases are also associated with more frequent and severe winter storms, whose impacts are amplified by the temporarily elevated sea level.

There have been 11 El Niño events recorded since the 1950's with the strongest ones occurring in 1982-83 and 1997-98 (Barnard et al., 2011). These storms caused landslides, floods, power outages, extreme tides, and dramatic changes in sensitive ocean fisheries, which had a major impact on California's economy (Field et al., 1999). Some of the primary damages in Santa Barbara from the 1982-83 El Niño included the partial erosion Leadbetter Beach and wave runup reaching Shoreline Drive, causing damage to the Yacht Club and Harbormaster's office. Additionally, wave debris was carried as far as Cabrillo Boulevard at Chase Palm Park (Griggs & Russell, 2012).

The effects of climate change on ENSO are still highly uncertain. There is evidence that recent El Niño events have been stronger than they have been for the past 150,000 years (Tudhope et al., 2001). Current climate models, however, have differing results on how climate change will affect ENSO. Certain aspects of climate change are predicted to increase the effects of El Niño events, while other aspects are projected to dampen the El Niño events (Collins et al., 2010).

2.3 The Effects of Erosion

Coastal erosion in Santa Barbara affects both bluffs and sandy beaches. Bluff erosion is considered irreversible because the rock face is broken down and cannot be replaced. Beach erosion, on the other hand, can be reversed or replenished with sand over time.

2.3.1 Bluff Erosion

In Santa Barbara, marine terraces are a prominent feature of the coastal environment. The bluffs within the City limits are composed of Monterey Shale, a brittle geologic formation, which is susceptible to physical and chemical weathering. Therefore, Santa Barbara bluffs have relatively higher vulnerability to erosion and landslides compared to other rocky cliffs (Norris, 1968; Griggs, Patsch, & Savoy, 2005).

Bluff erosion permanently changes the topology of a coastline, and can proceed slowly due to weathering or more quickly as a landslide. Rainstorms and excessive landscape irrigation can cause increased landslide hazards, while ocean waves can physically erode the base of the bluffs (Keller, 2011). Moreover, since most of the bluff tops of Santa Barbara slope seaward, increasing the hazard of large landslide events (Griggs et al., 2005).

One of the most recognizable forces affecting bluff erosion is wave activity. During high tides or during storms when sea levels are high enough to reach the bluff face, waves can directly erode the bluff, carrying bluff sediments to the ocean. Higher waves, like those that occur during high intensity storms, hold greater wave energy and therefore have a higher capacity to erode bluffs. Thus, wave activity is one factor contributing to sporadic episodes of bluff failure. Evidence of wave-cut bluffs can be seen along the Mesa, especially between Arroyo Burro Beach and One Thousand Steps public beach access point (**Figure 2.3**).

Figure 2.3: Wave-cut bluffs near Arroyo Burro Beach

Human activity is another important factor that contributes to a significant amount of bluff erosion. For example, watering non-native landscapes on the tops of bluffs may cause groundwater and a weakening of the bluff structure itself (Norris & Back, 1990). Development on the tops of coastal bluffs can feed excess water (from storm drains, etc.) into pipes, which are hung off the side of bluff faces. These pipes exert an external stress on the bluff face, which may cause accelerated erosion beneath the pipe. Small mammals and rodents associated with residential neighborhoods like the Mesa may also cause a weakening of the bluff structure by burrowing into the bluff face for shelter (Griggs et al., 2005).

There are many estimates on how rapidly the 4 miles of bluffs in Santa Barbara are eroding. This is mainly due to the time horizon chosen for the calculations, and to geologic differences in some locations along the bluffs that increase the hazard of landslides. The lowest projections indicate 0.25 to 0.83 feet per year (City of Santa Barbara, 2011), while more extreme projections indicate up to 3.3 feet per year in some locations (Hapke & Reid, 2007). Bluffs tend to fail at inconsistent intervals: large failures followed by many years of little to no erosion. For example, a landslide during the 1978 El Niño event caused heavy rainfall leading to bluff failure and the loss of two homes on the Mesa at El Camino de la Luz. Similarly, in January of 2008, Shoreline Park suffered a landslide causing the bluff to retreat by 38 feet (Zachary, 2008).

With the onset of sea level rise, bluff-top development may be threatened by accelerated bluff erosion. Griggs and Russell (2012) have recommended implementing a coastal bluff monitoring system, which has been incorporated into the City's Safety Element of the General Plan (City of Santa Barbara, 2013).

2.3.2 Beach Erosion

Beach erosion is caused by waves, currents, and wind, and can manifest as a reduction in beach width or more generally as a loss of beach sand (Griggs et al., 2005). Natural beaches change widths annually, eroding in the winter, and accreting in the summer. Seasonal erosion increases vulnerability in coastal cities to winter storms, making both long-term and short-term beach erosion a concern. Rising seas in the absence of human development can cause a natural inward beach migration. If development directly abuts the beach, however, the natural migration of the beach and ocean may be halted.

Human impacts and unusual weather conditions may affect the availability of sand to maintain beaches. Santa Barbara's harbor breakwater is one such human alteration that created both Leadbetter Beach and much of West Beach, but eventually eroded beaches further down the coast by depriving them of sand replenishment.

Leadbetter Beach, East Beach, and West Beach are collectively over 3 miles long and make up the City of Santa Barbara's wide, sandy beaches. Cabrillo Boulevard and the surrounding developments line these beaches. Park facilities, parking lots, roads, Stearns Wharf, and the Cabrillo Bathhouse were constructed on the back beach and serve as barriers preventing natural beach retreat.

The natural processes of the downtown beaches have been altered since the construction of the breakwater. For example, East Beach is nourished annually from Harbor dredging efforts and other maintenance (Griggs & Russell, 2012). Santa Barbara's coast has seen a relatively

stable beach profile with no net accretion or erosion. In the future, however, beaches are projected to primarily erode as water levels rise and beaches are not able to migrate inland (Revell, Marra, & Griggs, 2007).

Given the non-natural state of the beaches, as well as the small changes in Santa Barbara's beaches over time, beach erosion was not included in this analysis.

2.4 Hazard Preparedness

2.4.1 Economics of Santa Barbara relevant to Sea Level Rise

Coastal California property is some of the highest valued in the nation. Both public and private funds have been put towards protecting California's coastlines and minimizing the impacts of shoreline retreat and coastal inundation. Additionally, legislation such as the 1976 California Coastal Act has prompted communities to protect against threats to coastal public access (Griggs et al., 2005). Today's coastal communities are faced with many challenges for managing these popular and valuable resources, which affect the tourist industry, which contributes over $1 billion to Santa Barbara's local economy (Baker, 2003).

Disaster response and planning are critical for managing of City assets. Disaster planning for sea level rise related hazards can include ongoing maintenance of coastal facilities, education and training for disaster responders and citizens, and writing disaster management plans to effectively coordinate disaster response teams. For example, maintaining the function of tide gates and storm water pipes can reduce flooding in low-lying communities. One educational training program that the City offers is the Community Emergency Response Training (CERT) program through the Fire Department, a program that is offered to citizens of Santa Barbara and is free for City employees (Santa Barbara County Fire Department, 2015).

Coordinating disaster response can involve collaboration with local businesses and non-profits, as well as City and County Departments. The Santa Barbara County Multi-Jurisdictional Hazard Mitigation Plan includes City-specific information in City annexes as well as goals for the current conditions of hazards that may be influenced by sea level rise: coastal flooding and bluff erosion (Santa Barbara County Office of Emergency Management, 2011). The Safety Element of the City of Santa Barbara also includes practical goals and policies to begin to address sea level rise (City of Santa Barbara, 2013).

2.5 Existing Policies and Management of the Coastal Zone

Development in Santa Barbara's Coastal Zone is subject to the goals, policies, and zoning ordinance regulations set forth in the LCP (California Coastal Commission, 2014b). The City includes separate LCPs for the non-contiguous Airport and the rest of the City's coast. LCPs include a Land Use Plan–outlining the goals and policies for the CZ–and an Implementation Plan that includes zoning ordinances.

The CCC was granted the power to oversee and regulate coastal development by multiple legislative actions, but is guided predominantly by the California Coastal Act (1976), whose goal is to "protect, maintain, and where feasible, enhance and restore the overall quality of the Coastal Zone environment and its natural and artificial resources" (CCA, 1976, §30001.5).

Additional authority comes from the federal Coastal Zone Management Act of (1972), which was created to incentivize strategic use and management of coastlines for current and future generations ("Federal Consistency Program" (CCC), 2014).

For the first time since its initial adoption, the City is comprehensively updating its Land Use Plan portion of the LCP, in part through a grant from the CCC that requires the City to address the hazards of sea level rise within their LCP. The updated plan must be approved by the CCC.

One goal of this update is to make the LCP policies consistent with the City's updated General Plan. The General Plan guides development for the entire City and includes goals and policies that address climate change in general as well as sea level rise (City of Santa Barbara, 2011). Its Safety Element (2013) contains most of the policies relevant to sea level rise, and is guiding the City as it updates its Land Use Plan. The Safety Element incorporates many of the suggestions from the City's Climate Action Plan (2012), including recommendations from Griggs and Russell (2012).

2.6 Overview of Vulnerability Assessments

A vulnerability assessment measures the vulnerability of an area to a hazard by characterizing a hazard by the extent of physical, social, or economic damage that might happen if the community is exposed to the hazard. Definitions of terms used in vulnerability assessments can be found in **Appendix A**. The documents that directly influenced this group project are discussed below.

2.6.1 Draft Sea-Level Rise Policy Guidance

The most relevant guiding document to this study is the Draft Sea-Level Rise Policy Guidance (2013) authored by the California CCC; the final guidance document is expected to be published in the spring of 2015. This document will recommend that all municipalities required to produce an LCP conduct a vulnerability assessment for sea level rise and develop policies to address those long-term risks. The CCC guided the elements of analysis in this current group project vulnerability assessment by emphasizing the importance of looking at critical infrastructure, human populations, recreation and public access, and ecological resources.

2.6.2 Adapting to Sea Level Rise: A Guide for California's Coastal Communities

In this document, researchers Nicole Russell and Dr. Gary Griggs outline a basic methodology for conducting local vulnerability assessments in California (Russell & Griggs, 2012). The California vulnerability assessment guidance document helps managers and researchers to assess their own city's vulnerability in a way that is comparable across jurisdictions. Griggs and Russell define a vulnerability assessment as "an evaluation of the degree of the community's exposure to various coastal hazards" that includes "the magnitude of the damages or losses". They consider adaptation to be a "risk management strategy for an uncertain future" (2012, p. 12). This current group project vulnerability assessment adopted the basic methodology for conducting a vulnerability assessment from Russell and Griggs' guidance document (Russell & Griggs, 2012).

2.6.3 City of Santa Barbara Sea Level Rise Vulnerability Study

Griggs and Russell also assessed the vulnerability of Santa Barbara (2012); their case study took a preliminary look into the types of hazards that Santa Barbara may encounter with rising sea levels. Their study included two major components: the likelihood of an event occurring in the future, and the magnitude of the impact of that event. They also assessed the City's "adaptive capacity," or the ability of the community "to respond to sea-level rise and its associated impacts" (Griggs & Russell, 2012, p. 13). This current group project vulnerability assessment includes updated sea level rise projections, topographic data, and supplementary recommendations to Griggs and Russell's case study (Griggs & Russell, 2012).

Some of the primary findings from Griggs and Russell's study were that the risks of wave damage to the City would be high by 2050, while flooding and inundation risks would remain relatively low. The City's adaptive capacity was determined to be moderate in these situations, and Griggs and Russell recommended a strategy of "beach retreat" as the best option for the City. Risks of bluff retreat by 2050 were comparatively lower than wave damage risks, but the ability of the City to adapt to bluff erosion was also determined to be low. Beach inundation by 2050 was the lowest projected risk, but by 2100 was expected to become a high threat. Wave damage, inundation, and bluff erosion were all considered to be a very high threat by 2100.

The Griggs and Russell study (2012) was designated as an important baseline within the CCC grant that funded this group project vulnerability assessment for the City.

2.6.4 The Sea Level Rise Vulnerability Assessment for the City of Los Angeles

The University of Southern California Sea Grant program, in partnership with the City of Los Angeles, prepared the Sea Level Rise Vulnerability Assessment for the City of Los Angeles. These institutions developed an adaptation planning process, which included a "methodology to help the City identify the vulnerabilities of sea level rise of its assets, resources and communities" (Grifman et al., 2013). Their study divided its analysis and results into three categories: exposure, sensitivity, and adaptive capacity, which were also used in this current group project vulnerability assessment.

2.6.5 Goleta Slough Sea Level Rise Report Draft

The Santa Barbara Airport is owned by the City, but is responsible for its own LCP. The Airport is in the process of preparing a sea level rise report for the City-owned area within Goleta Slough (Goleta Slough Management Committee, 2014). The Goleta Slough report will identify policy changes and management strategies to help bolster the adaptive capacity of the slough, primarily with respect to sensitive habitat and infrastructure.

3. Methods

This group project vulnerability assessment is organized into three parts: exposure, sensitivity, and adaptive capacity. These three measures are commonly used as a way to estimate the total vulnerability of an area to sea level rise. Exposure refers to the projected spatial extent of sea level rise hazards on the land surface. Sensitivity is a measure of the internal characteristics of exposed geographic features that may increase the feature's susceptibility to a sea level rise hazard. Finally, adaptive capacity is the ability of the resource to maintain its function after being exposed to a hazard. Adaptive Capacity is used to explore potential strategies to reduce the risk of damage caused by projected hazards. The following methods pertain to the determination of exposure and sensitivity used in this analysis and a discussion of adaptive capacity is located in **Chapter 5**.

3.1 Exposure Modeling Methods

This analysis determined exposures for three hazards: permanent inundation due to sea level rise, a 100-year storm surge enhanced by sea level rise, and erosion. All three hazards were modeled using a NOAA coastal LiDAR hydro-flattened bare earth digital elevation model (DEM) from 2010 (NOAA, 2012). LiDAR, or Light Detection and Ranging, is a remote sensing technique that can be "used to generate high resolution topographic data" (NOAA, 2015b). This LiDAR DEM has a horizontal resolution of 1 meter, a horizontal accuracy of 50 cm, and a vertical accuracy of 9.4 cm. This group project analysis was conducted using North American Datum of 1983 (NAD83) as the horizontal datum projected into California V FIPS in feet (the City's default map projection), and the North American Vertical Datum of 1988 (NAVD88) in meters for elevations.

3.1.1 Sea Level Rise Permanent Inundation Modeling

Modeling the extent of inundation due to sea level rise requires both a land surface and a water surface. The DEM was used as elevation data for the land surface and a single-value approach was used for the water surface (also known as a bathtub model). A single-value water surface simply means that a single numerical value was used to represent the water level across the entire study area. Two other approaches used to construct an ocean surface are modeled water surfaces and interpolated water surfaces. This study uses the simplified single-value water surface because the study area is too small for the available and relatively low-resolution modeled water surfaces, and the single tide gauge in the study area makes it pointless to construct an interpolated water surface.

This assessment examined the extent of inundation for nine different values of sea level rise as shown in **Table 3.1**. These values are taken from the NRC's sea level rise report (2012) and are currently considered the best available science for sea level rise projections in California (CCC, 2013)

Table 3.1: Sea level rise scenarios adapted from NRC 2012.

Projection	Year	Sea Level Rise (m)
Low	2030	0.05
	2050	0.13
	2100	0.44
Medium	2030	0.15
	2050	0.28
	2100	0.93
High	2030	0.30
	2050	0.61
	2100	1.67

Each sea level rise value was added to the determined elevation of Mean Higher High Water (MHHW) for Santa Barbara (see **Figure 3.1**, **Figure 3.2**, **Figure 3.3**). Mean Higher High Water is defined as the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (NOAA, 2013). The MHHW level observed from the Santa Barbara tide gauge is 1.645 m (5.40 ft) relative to NAVD88 (NOAA, 2015a).

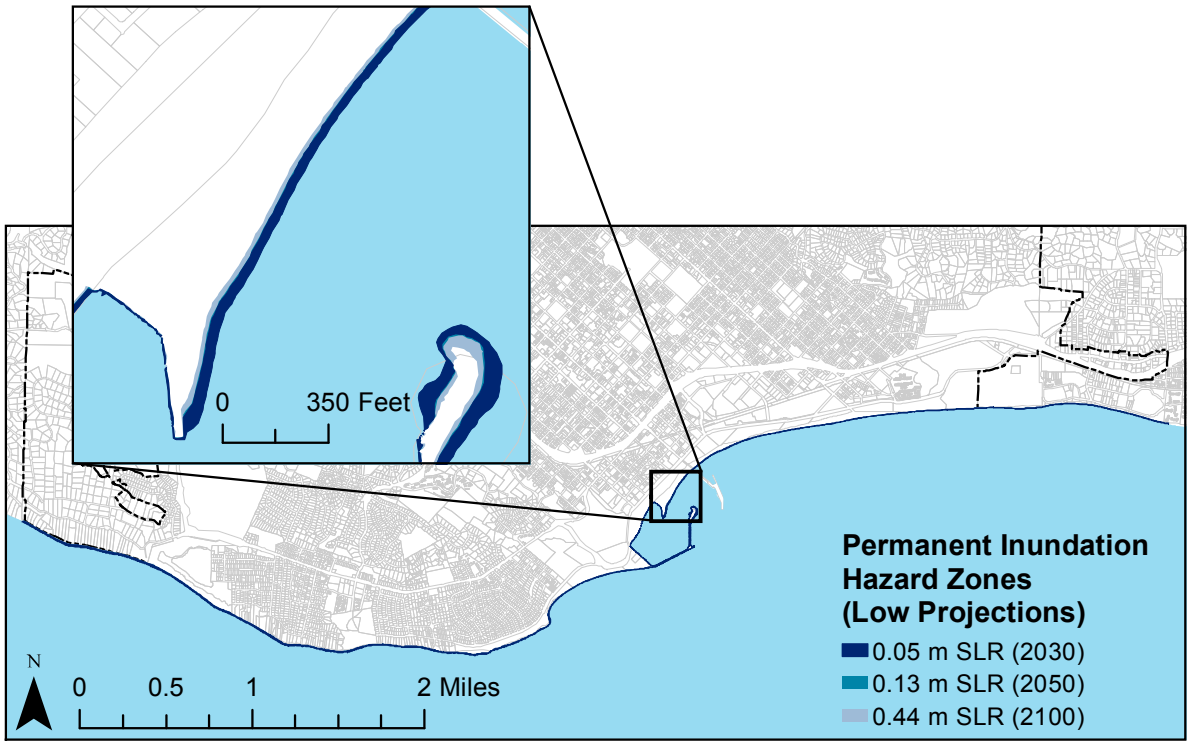


Figure 3.1: Low sea level rise projections for 2030, 2050, 2100.

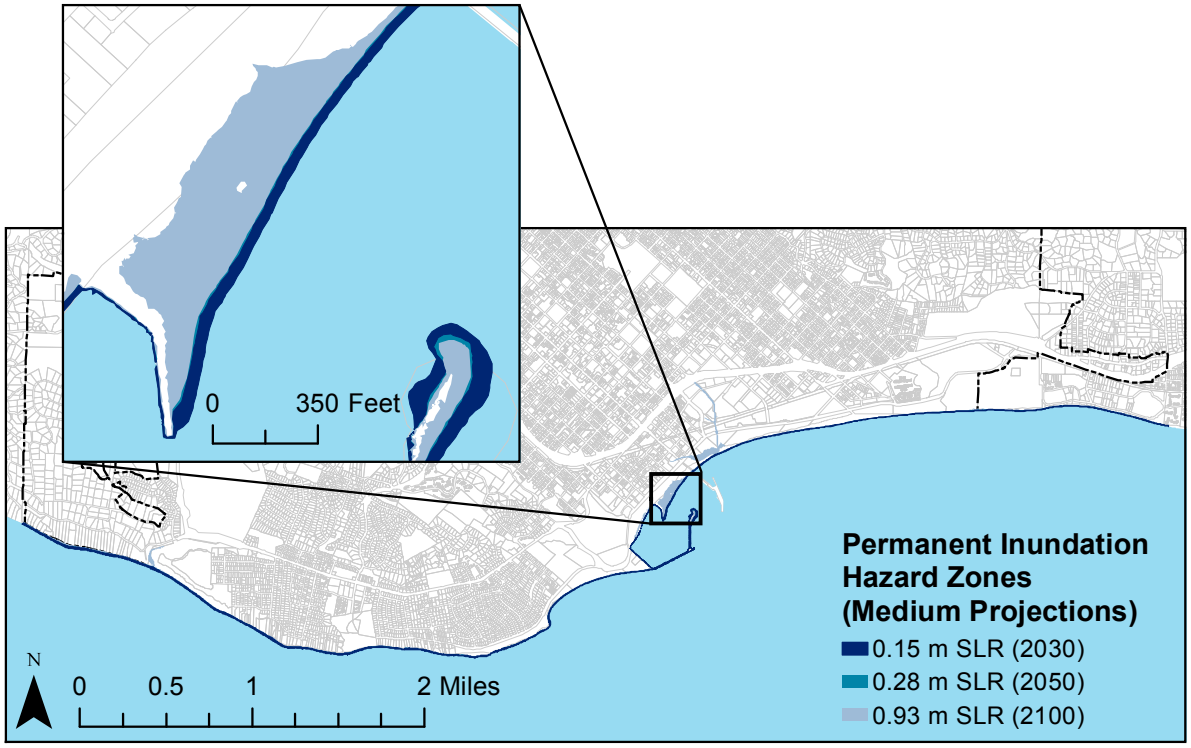


Figure 3.2: Medium sea level rise projections for 2030, 2050, 2100.

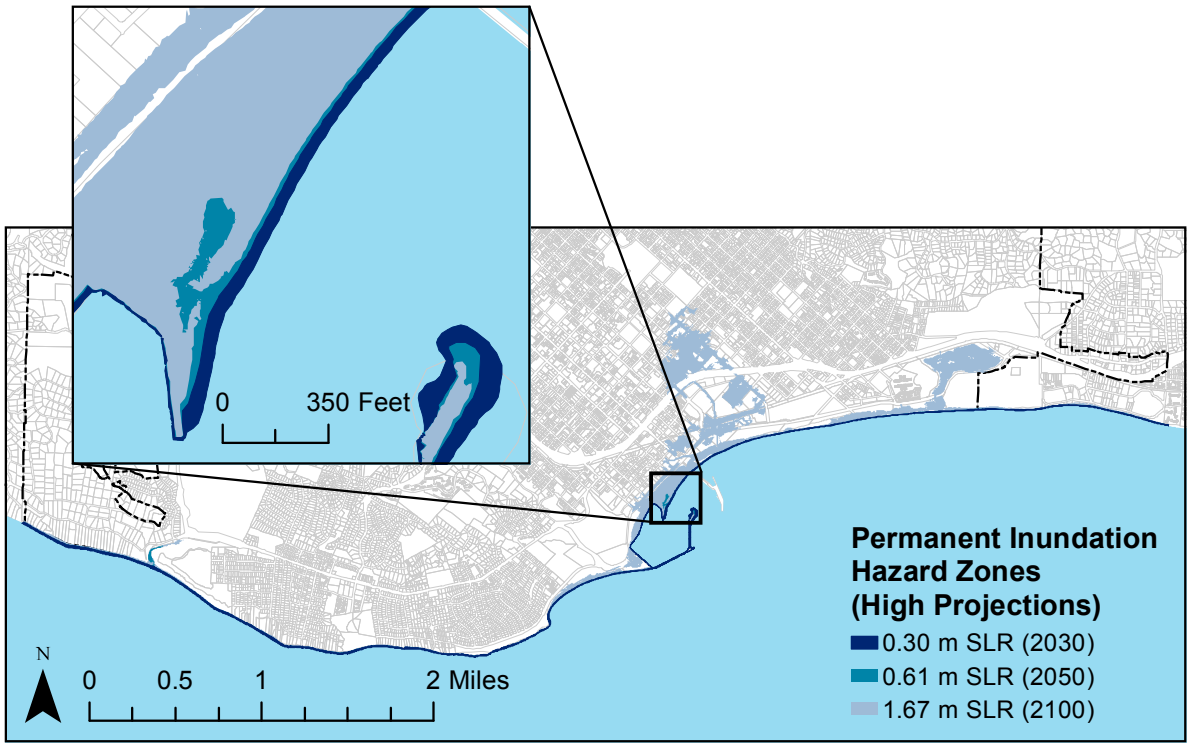
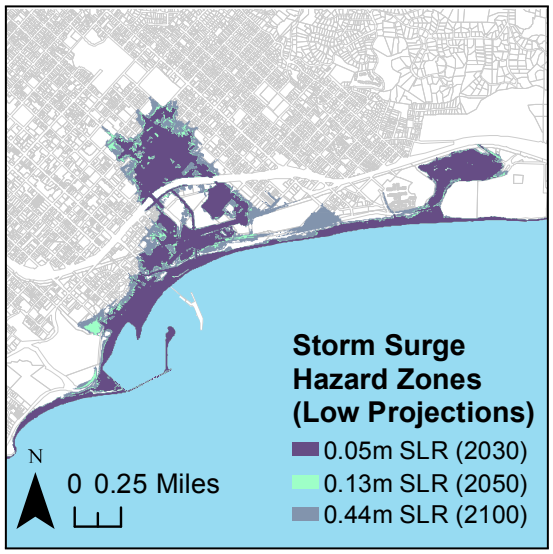


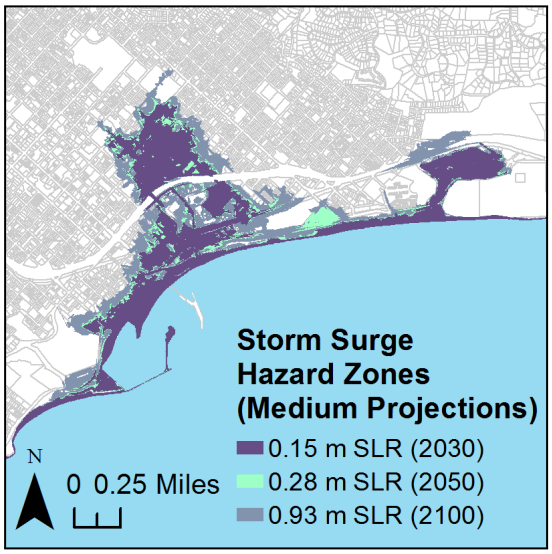
Figure 3.3: High sea level rise projections for 2030, 2050, 2100.

3.1.2 Storm Surge Modeling

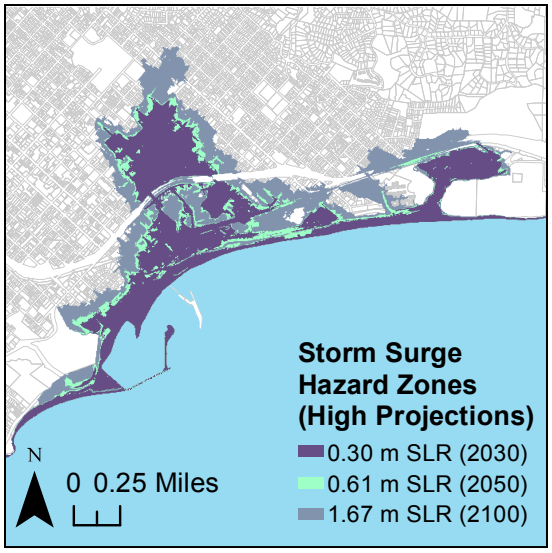
To assess storm surge exposure, FEMA's modeled Base Flood Elevations (BFEs) corresponding to a 100-year storm were added to the sea level rise values (**Figure 3.4**). BFEs were obtained from Santa Barbara Flood Insurance Rate Maps (FIRMs) for zone VE, corresponding to the wave runup zone. Methods for calculating the inland extent of flooding were identical to the above methods for inundation.



(a) Low projections



(b) Medium projections



(c) High projections

Figure 3.4: 100-year storm surge hazard zones given sea level rise projections.

3.1.3 Bluff Erosion Modeling

Bluff erosion hazards were projected using average erosion rates for Santa Barbara bluffs over a time horizon of 75 years, a timeframe derived from the planned lifetime of a building or structure. This method ignores the spatial and temporal variations of large landslide events, which occur at unpredictable times. Given a long enough time period, however, historic rates of erosion can capture much of this variation. Therefore, our results indicate what the bluffs may look like in 75 years, but they do not capture the hazards of a very large landslide that could occur along the most susceptible geologic substrates.

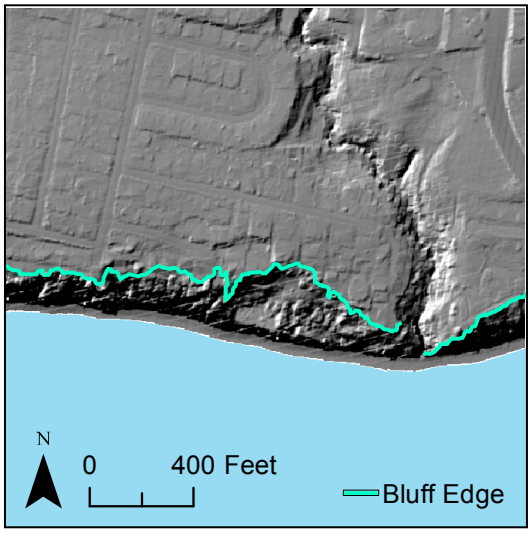


Figure 3.5: Estimating a bluff edge from LiDAR imagery.

In order to determine the bluff edge of the City bluffs, a hill-shaded version of the DEM was used. The bluff edge was hand-digitized following the methodology of the USGS (Hapke & Reid, 2007) as shown in **Figure 3.5**. Hill-shading allowed for the visual inspection of known locations with more than one possible bluff edge. For example, there may be more than one bluff edge at El Camino de La Luz, the Clark Estate bluffs, and at the western edge of the City (look closely at the middle of **Figure 3.5**). The defined bluff edge was then set back by three erosion rates: 6, 12, and 24 inches/year. The historical range of average bluff retreat rates in Santa Barbara is 6 to 12 inches per year to account for the historical range of average bluff retreat in Santa Barbara (Griggs et al., 2005). To account for a heightened effect of sea level rise on erosion rates, a doubled rate of 24 inches/year was selected based on the literature (see **Figure 3.6**, (Griggs & Russell, 2012)).

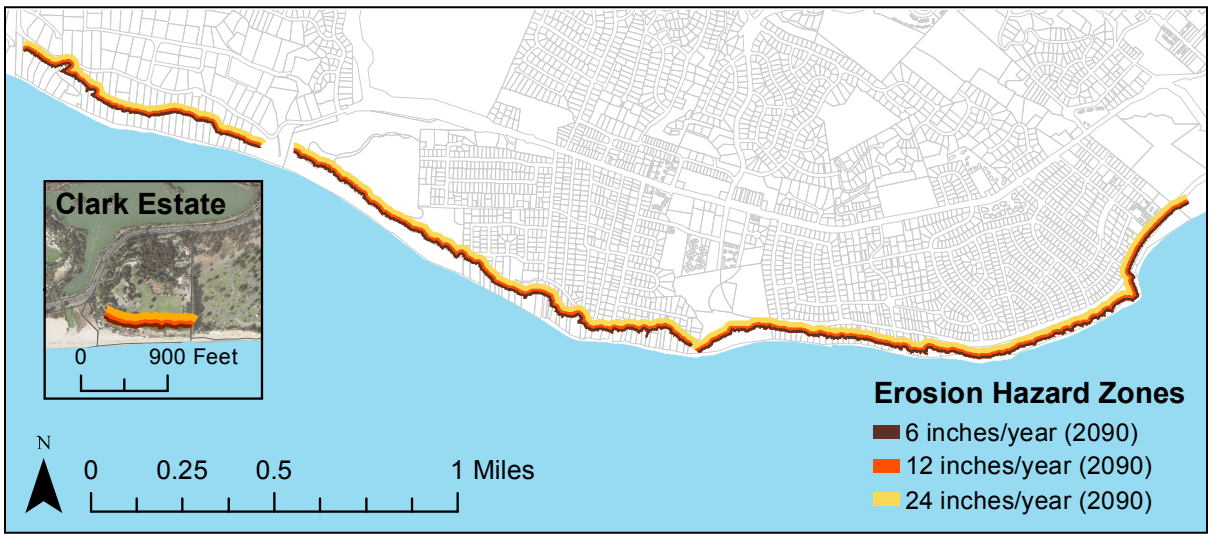


Figure 3.6: 75-year bluff erosion projections.

3.2 Sensitivity Methods

Sensitivity was defined in two ways for this group project analysis. For the critical infrastructure, recreation and public access, and ecological resources elements, sensitivity is a measure of how important the resource is to the community of Santa Barbara. For the human populations element, sensitivity refers to how susceptible a population is to the effects of a hazard based on various demographic qualities. The sensitivity of each geographic feature was assigned a high/medium/low ranking for all elements in order to prioritize features for adaptation. The methods used to analyze sensitivity within each element are described below.

3.2.1 Critical Infrastructure Element Methods

Data

The analysis of Santa Barbara's critical coastal infrastructure used multiple datasets to cover the rather broad definition of critical infrastructure. Three sectors of critical infrastructure were investigated: transportation, building structures, and water transport systems.

Transportation data consisting of roads, the railroad, bike paths, and parking lots came directly from the City (City of Santa Barbara, 2014-2015). A list of critical facilities in Santa Barbara was compiled based on the 2011 Santa Barbara County Multi-Jurisdiction Hazard Mitigation Plan and the Safety Element for the City of Santa Barbara General Plan (2013) (**Appendix C**). Building footprints from the City were then used to compile the critical facilities for the analysis. Finally, water delivery systems data consisting of: storm drains, sewer structures, and water mains were obtained from the City.

Analysis

Critical infrastructure can broadly be defined as the resources that contribute to the functioning of society. Sensitivity was ranked qualitatively based on how essential a resource is to maintain the basic functions of a city. High sensitivity rankings were assigned to resources crucial to maintaining human health and safety medium for those fundamental to general City functions, and low rankings for resources that can be easily relocated to continue operations (**Table 3.6**).

Table 3.2: Sensitivity ranking for critical infrastructure resources.

Rank	Classification
High	Structures Critical for Public Health and Safety
Medium	Structures Important for General City Operations
Low	Structure Useful to City

3.2.2 Human Populations Element Methods

Data

To analyze human populations, demographic data from the 2008-2012 American Community Survey (ACS) 5-Year Estimates were used (U.S. Census Bureau, 2013). Although this dataset, at the block group level, has a higher margin of error compared to other options such as the U.S. Census 2010 (U.S. Census Bureau, 2011), it contains a majority of the demographic

variables of interest. Census data were also analyzed for comparison. For further information on ACS margin of error, an explanation of the difference between the ACS and Decennial Census, and a comparison of ACS and Census data at the block group level, see **Appendix C**.

Population demographics in Santa Barbara will change in the future, potentially making the data used in this analysis obsolete. Instead of attempting to predict these changes, this analysis aimed to capture the current demographic sensitivity. The benefit of this type of analysis is that an understanding of today's demographic sensitivity can be used to create adaptation plans that reduce the vulnerability of certain areas exposed to a hazard.

Analysis

Several studies were reviewed to identify demographic categories to evaluate sensitivity in the context of a sea level rise hazard. Demographic categories were chosen based on those used in the document Sea Level Rise Impacts and Flooding Risks in the Context of Social Vulnerability: An Assessment for the City of Los Angeles. These categories include age, socioeconomic status, housing conditions, and isolation (Ekstrom & Moser, 2013).

Several variables were selected from the ACS that address each category to determine demographic sensitivity in Santa Barbara (See **Table 3.3**). For example, indicators of isolation in a population include variables such as populations that are living alone, people with poor English, and those with no access to motor vehicles (See **Appendix C** for the justification of each demographic variable). Many of these variables were drawn from the Pacific Institute's white paper entitled The Impacts of Sea Level Rise on the San Francisco Bay (2012).

Table 3.3: Demographic variables used for human population sensitivity analysis.

Category	Variable
Age	Householders Over 65 Households with Members Under 18
Socioeconomic Status	Single Parent Households Households Under Poverty Level
Housing Conditions	Households Renting Living in Household with 5+ people
Isolation	Householder Living Alone Non-English Speaking Households Households with No Vehicle Access

To rank the block groups according to their relative sensitivity, a quantiles approach was used to divide the range of populations across each variable into three bins. Quantiles are defined as values taken at regular intervals from the inverse of a cumulative distribution function (CDF), thereby dividing ordered data into equal-sized subsets. Each variable in a block group was assigned a point value from one to three based on the bin the population fitting that variable was in, where the bin with the highest population received three points and the bin with the lowest population received one point. These points were aggregated across variables to achieve an overall score for each block group. The range of scores was then divided into three equal-sized bins, where blocks with the highest scores received a "high" sensitivity rank, the middle scores were considered "medium" sensitivity, and the lowest scores were identified

as "low" sensitivity areas.

Table 3.4: Sensitivity ranking for human populations.

Rank	Classification
High	Block Group in Top Quantile for Demographic Variables
Medium	Block Group in Middle Quantile for Demographic Variables
Low	Block Group in Bottom Quantile for Demographic Variables

The above methods were also used to additionally analyze demographic data from the US Decennial Census of 2010. The results of this analysis as well as a comparison with the ACS analysis are explained in detail in **Appendix D**.

3.2.3 Recreation and Public Access Element Methods

Data

The analysis of recreation and public access used the CCC's public access dataset as well as a list of known recreational facilities within the Coastal Zone from the City (California Coastal Commission, 2014a). CCC data included spatial point references to a number of coastal public access locations as well attributes for each point that identified important recreational assets.

Analysis

All data points were converted into spatially relevant polygons through a combination of digitization and the use of parcel data. Missing and incorrect attribute data within the CCC's dataset were added or corrected for each Santa Barbara location. When necessary, separate data points were condensed into one spatial site. The exposure of the Harbor and Stearns Wharf was analyzed qualitatively due to a lack of elevation-derived exposure data for these areas.

A subset of the total list of attributes from the CCC data was selected to represent the degree to which a resource is developed, which was used to define sensitivity for this analysis. An example of attributes used can be seen in **Table 3.5**. For a complete list of Recreation and Public Access variables used to analyze sensitivity, see **Appendix C**.

Table 3.5: Partial list of attributes used for the analysis of Recreation and Public Access.

Category	Variable
Transportation Access	Accessible by Public Transportation Parking Lot or Street Parking Available
Support Facilities	Showers Restroom
Recreation	Disabled Access Available Boating Facilities Available

A simple, evenly-weighted multiple criteria assessment was used to rank sensitivity. A site received a point for every attribute it contained. The number of attributes within a site was

summed to create a score, and the range of scores across sites was divided into three bins of equal width–one each for Low, Medium, and High sensitivity. The score that the site received determined its overall sensitivity ranking (**Table 3.6**).

Table 3.6: Sensitivity ranking for recreation and public access resources.

Rank	Classification
High	Sites in Top Quantile for Number of Attributes
Medium	Sites in Middle Quantile for Number of Attributes
Low	Sites in Bottom Quantile for Number of Attributes

3.2.4 Ecological Resources Element Methods

Data

The City provided ecological data from a Biological Resource Report for the City of Santa Barbara. This study was conducted by URS in 2006 to update the Master Environmental Assessment of Santa Barbara (URS, 2008). Specifically, three datasets were used: creeks and wetlands, wildlife areas, and sensitive fish habitat.

The creeks and wetlands data layer contains riparian, wetland, and estuary areas as well as all major creeks within the city limits. The wildlife area data represents areas that are important for nesting, foraging, congregation and movement and includes examples of species present in each area. Finally, the sensitive fish habitat layer describes Santa Barbara creeks that are designated habitat for the tidewater goby and/or the southern California steelhead, which are both federally listed endangered species (URS, 2008).

Analysis

The Coastal Act defines an environmentally sensitive habitat as, "any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and developments" (CCA, 1976, §30107.5). Although the City does not have any CCC-designated ecologically sensitive habitat areas within its limits, there are many ecological resources that fit the criteria. The sensitivity of ecological resources was determined based on designated habitats for federally listed species, as shown in **Table 3.7**.

Table 3.7: Sensitivity ranking for ecological resources.

Rank	Classification
High	Federally Listed Endangered Species Habitats
Medium	Federally Listed Threatened Species Habitats
Low	No Federally Listed Species Habitats

This sensitivity ranking addresses the classification of an ESHA based on the presence or absence of rare habitats and species. The adaptive capacity section of this report addresses concerns of human disturbance and potential long-term effects of sea level rise on these habitats.

4. Results

Overall results indicate that storm surge will cover a much larger geographic area of Santa Barbara than permanent inundation. This flooding, however, will be temporary. Factors influencing floodwater height and duration include storm drain capacity and hydrology, precipitation patterns, tidal and wave dynamics, existing conditions, and the availability of electricity. Projected sea level rise values will be referred to with the acronym "SLR."

4.1 Critical Infrastructure Element

4.1.1 Transportation

Roads

Exposure: Critical transportation infrastructure exposed to sea level rise related hazards include roads, bikeways, parking lots, and the railroad (**Figure 4.1**). Approximately 21 miles of roads in Santa Barbara are at risk of experiencing at least one of the projected hazards considered in this group project analysis. Many of these roads exist in low-lying areas. Most notably is Cabrillo Boulevard, which is at risk of both permanent inundation and flooding due to a 100-year storm surge. There are also many roads located near the bluff edge along the Mesa at risk of erosion. No roads were found to be at risk of permanent inundation until 0.93 m SLR (2100 Medium). This amount of rise could affect about 0.04 miles (232 ft) of Cabrillo Boulevard and lower State Street, mainly where the roads pass over the creeks. With 1.67 m SLR (2100 High), roughly 4.6 linear miles of roads are projected to be inundated including much of Cabrillo Boulevard, some of lower Anacapa Street, the Garden Street underpass, and some of Haley Street, Helena Avenue, Calle Cesar Chavez, and Gutierrez Street. A 100-year storm surge is projected to affect many more roads in Santa Barbara than any amount of inundation alone (**Figure 4.2**).

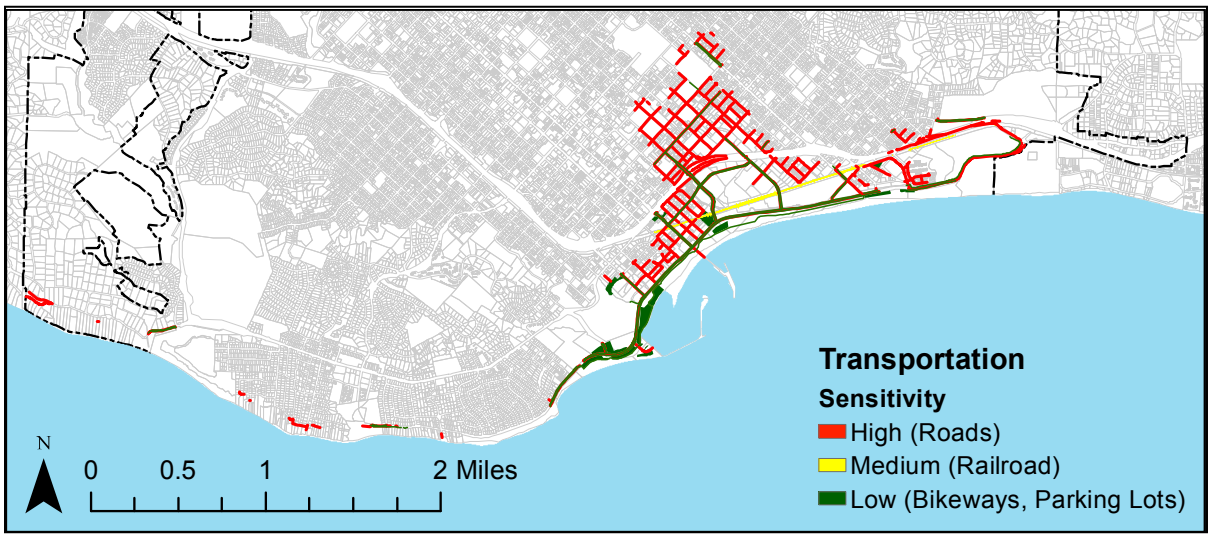
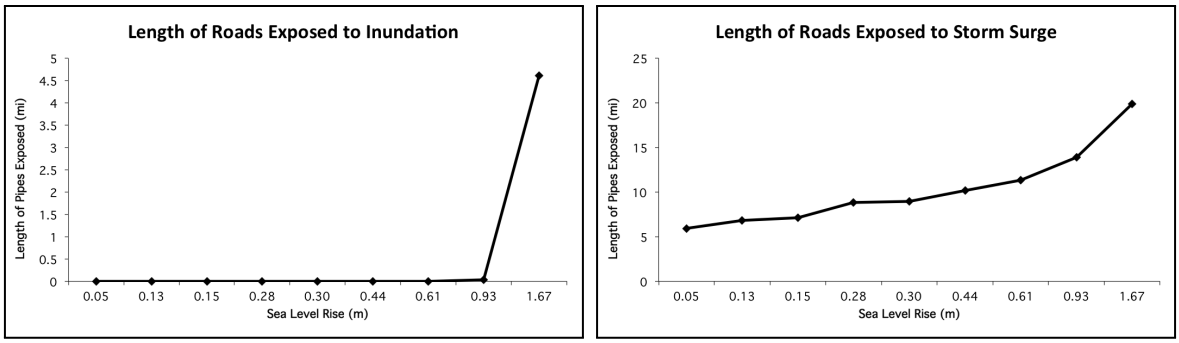


Figure 4.1: Critical transportation sensitivity within erosion, storm surge, and inundation hazard zones.



(a) **(b)**

Figure 4.2: Roads within inundation and storm surge hazard zones.

Erosion hazards also threaten a significant portion of roads in Santa Barbara. Shoreline Drive is the main road that is affected, with about 0.3 linear miles (1600 ft) of right-of-way threatened using an erosion rate of 6 inches/year, and 0.5 linear miles (2400 ft) with an erosion rate of 12 inches/year. Finally, with an erosion rate of 24 inches/year 1.1 miles of roads are at risk including upper Shoreline Drive, Santa Cruz Boulevard, Mohawk Road, and Edgewater Way.

Sensitivity: Roads in Santa Barbara are identified as high sensitivity resources. Roads are the main access and evacuation points for emergency situations, and they provide transportation opportunities for citizens. When roads are flooded or blocked for any reason, citizens can become dangerously isolated from law enforcement and medical services.

Railroad

Exposure: There is one main railroad that runs through the Coastal Zone of Santa Barbara. The railroad is not projected to experience permanent inundation until 0.93 m SLR (2100 Medium) and even then it only affects about 200 linear feet of track. But with 1.67 m SLR (2100 High), this number increases to about 15,000 feet of railroad track inundated. A 100-year storm is also the biggest threat to this resource and is projected to flood 17,000 to 37,000 feet of track (see **Appendix D** for tables of railroad within hazard zones). The railroad would not experience any bluff erosion hazards within the City limits.

Sensitivity: The railroad is identified as a medium sensitivity resource because it is an important mode of transportation for people and goods. It could serve as an evacuation method for households with no vehicle access. The train brings fewer than ten percent of tourists to the Santa Barbara area (Destination Analysts, Inc., 2013). If more tourists begin to arrive via train, the railroad will become a more economically important resource for the City.

Parking Lots

Exposure: Many parking lots along the coast are used mainly for recreational purposes, but they are included in this section because they are identified as a critical piece of the transportation system within the City. Parking lots in the Coastal Zone are potentially exposed to permanent inundation starting at 0.44 m SLR (2100 Low) with the Harbor lot along Shoreline Drive most exposed. These results are shown below in **Table 4.1**:

Table 4.1: Area of Waterfront Parking Lots Exposed to Permanent Inundation with 1.67 m SLR (2100 High).

Parking Lot	Area Exposed (sqft)	Area Exposed (acres)
Palm Park	46,000	1.06
Garden Street Lot	20,000	0.46
Mason Street	25,000	0.57
Harbor Boat Launch Ramp	119,000	2.74
Harbor Main Lot	151,000	3.45
Harbor Commercial Area and 90 Minute	66,000	1.52
Harbor West	16,000	0.36

There are no parking lots that are threatened by erosion hazards in this analysis.

Sensitivity: Parking lots in the Coastal Zone are ranked as low sensitivity resources because they do not facilitate operations during emergency situations. At some cost, parking lots could be provided in less hazardous areas that are still near the resources that the public wants to access. Parking lots, especially those along the waterfront, serve as important sources of revenue during everyday operations. These economic considerations were not included in this analysis. However, the importance of available parking (parking lots or ample street parking) were included as one variable of analysis within the recreation and public access element.

Bikepaths

Exposure: Bikepaths are not projected to experience permanent inundation until 0.93 m SLR (2100 Medium) where 0.24 miles of the bikepath along Cabrillo Blvd. become exposed. At 1.67 m SLR (2100 High), 4.2 miles of bikepaths become exposed including some paths in the downtown area. There are stretches of bike paths located along the Mesa that are also exposed to the effects of erosion. Bikepath exposure to inundation, storm surge, and erosion can be seen in **Appendix D**.

Sensitivity: Bikepaths serve as important means of recreation and transportation. While they provide for increased safety for people who commute via bicycles, they are of a relatively low sensitivity in the category of critical infrastructure. Bikepaths add to the safety and convenience of residents and tourists, but in a storm condition it will be much more important to ensure the continued functioning of the roads themselves. While bikepaths, especially the multi-modal bikeway along Cabrillo Boulevard, add to the community character of the City and its tourism appeal, specific economic considerations were not included within this analysis.

4.1.2 Critical Structures

Of the 18 critical building resources included in this analysis (see **Appendix C**), ten are situated within at least one projected hazard zones (see **Figure 4.3**). Of these ten resources, four are threatened by permanent inundation with 1.67 m SLR (2100 High) and none are exposed to bluff erosion hazards.

Figure 4.3: Critical facilities within erosion, storm surge, and inundation hazard zones.

Santa Barbara Fire Station 2

Exposure: Santa Barbara Fire Station 2 (located at 819 Cacique Street) includes three structures on the property; all structures are potentially exposed to a 100-year storm surge coupled with 1.67 m SLR (2100 High). This resource is only exposed at the most extreme hazard scenarios used in this analysis and therefore has a relatively low overall exposure.

Sensitivity: Fire Station 2 and all fire stations within the City limits are considered a high sensitivity resource, as they are essential to maintaining the health and safety of the citizens of Santa Barbara. In disaster-type situations, such as a 100-year storm or fire, emergency response is crucial to protect the population. Fire Station 2 specifically responds to the lower Eastside, Coast Village Road, Alston and Eucalyptus Roads areas. Station 2 firefighters are certified as California State Fire Marshal hazardous materials spill response specialists and will respond with HazMat 1 to mitigate chemical, radiological, or other spill problems. They are part of a regional hazardous materials response team including firefighters from Carpinteria Summerland Fire Department, and Montecito Fire Department (City of Santa Barbara Fire Department, 2015).

El Estero Wastewater Treatment Plant

Exposure: El Estero Wastewater Treatment Plant includes 16 structures on the property. Although none of the structures would be affected by permanent inundation, 1.67 m SLR (2100 High) is projected to surround the property, potentially cutting off access (**Figure 4.4**). These structures are, however, affected by sea level rise in combination with a 100-year storm surge. One structure is exposed to a 100-year storm surge combined with 0.28 m SLR (2050 Medium), five structures with 0.61 m of SLR (2050 High), 15 structures with 0.93 m SLR (2100 Medium), and all 16 structures for a 100-year storm surge and 1.67 m SLR (2100 High).

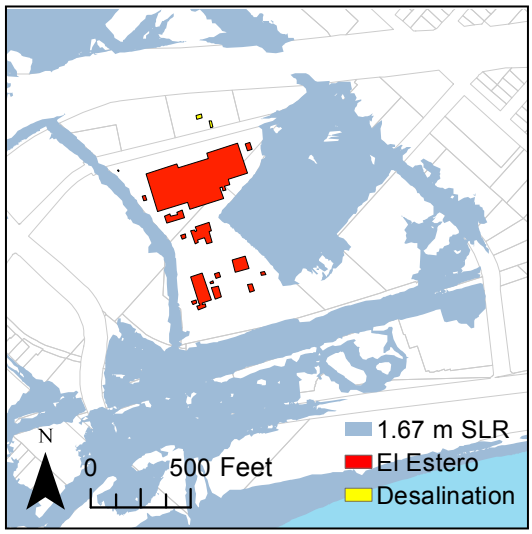


Figure 4.4: El Estero Wastewater Treatment Plant with inundation hazard zone.

Sensitivity: El Estero Wastewater Treatment Plant is ranked as a high sensitivity resource because it is critical to the health and safety of the City of Santa Barbara. An average of 8 million gallons of wastewater per day arrives at El Estero by means of underground pipes and pump stations (City of Santa Barbara, 2015a). Pumps are particularly vulnerable to sea level rise; the pump at El Estero is one of four pump stations within the Coastal Zone. A malfunction such as excess water input to this plant could result in the discharge of raw or partially treated wastewater into the ocean or into residential neighborhoods.

Ortega Groundwater Treatment Plant

Exposure: The Ortega Groundwater Treatment Plant consists of four structures and only one would be exposed to storm surge combined with 1.67 m SLR (2100 High).

Sensitivity: The Ortega Groundwater Treatment Plant is considered to have high sensitivity because it is an important source of water for the City, especially during drought conditions. It currently treats water from one of the two groundwater basins currently used by the City, with the City pumping roughly 1,000 acre feet per year of groundwater (City of Santa Barbara, 2015b). There have been historic saltwater intrusion events in this basin in the late 1970s because of heavy pumping in municipal wells (Public Works, 2012). However, due to improved groundwater pumping practices, Storage Unit 1 is currently not at risk of saltwater intrusion, even with the onset of sea level rise and related hazards. Further studies of groundwater management and saltwater intrusion issues are underway by the City and federal government. The City plans to continue to rely on groundwater sources into the future, making the Ortega Groundwater Treatment Plant a vital resource for City functioning.

Charles Meyer Desalination Plant

Exposure: The Charles Meyer Desalination Plant consists of two structures and–similar to the El Estero Wastewater Treatment Plant–is projected to have water surrounding the plant with 1.67 m SLR (2100 High). One structure may be exposed to flooding from a 100-year storm surge with 0.61 m SLR (2050 High), while both structures are predicted to be exposed to flooding from a 100-year storm surge with 0.93 m SLR (2100 Medium).

Sensitivity: The Charles Meyer Desalination Plant is considered a medium sensitivity resource because it is not essential for the health and safety of Santa Barbara. The plant is not currently functioning because of high operational costs in times of non-drought. However, due to persistent drought, the City is currently in process of re-commissioning the plant to ensure reliable drought supplies should the dry weather persist through additional years (S. Greer, personal communication). If water availability continues to decline, this plant may become an important source of water for the City.

Laguna Pump Station and Tide Gate Facility

Exposure: The exposure of the Laguna Tide Gate and Pump Station cannot simply be measured by an in/out analysis of water levels. The ocean tides are expected to permanently touch the tide gate with 0.93 m SLR (2100 Medium), which may indicate when the tide gate will act more as a seawall than a tide gate. These structures are designed to deal with floodwater and water in general.

Sensitivity: Laguna Pump Station is a high sensitivity critical resource to the City because, along with the tide gate, it provides protection from both coastal and river flooding. The tide gate keeps high water levels from flooding into the City, and the pump station pumps excessive flows into Laguna Lagoon during times of high precipitation. When this is overwhelmed, as it was in 1995, areas such as the Garden Street underpass may flood.

City of Santa Barbara Public Works Yard

Exposure: The Santa Barbara Public Works Yard includes three total structures and would not be exposed to permanent sea level rise inundation. One structure may be exposed to flooding during a 100-year storm surge with 0.05 m SLR (2030 Low) and all three structures are within the projected 100-year storm surge hazard zone with at least 0.13 m SLR (2050 Low).

Sensitivity: The Santa Barbara Public Works Yard is considered a medium sensitivity resource. These yards contain equipment necessary for the Public Works Department to manage the infrastructure of the City. These structures are important to keep the City functioning properly but in an emergency situation are not essential to maintaining health and safety of citizens.

For the analysis of low sensitivity Critical Infrastructure for the City, please see **Appendix D**.

4.1.3 Water Transport Systems

Three types of water transport systems were considered in this analysis: sewage systems, storm drains, and water delivery systems. While many of these structures are located below ground, they can still suffer damages due to ground-level inundation, flooding, infiltration, or erosion. Additionally, pipes that outfall to the coast are vulnerable to being blocked by high sea levels, increasing the amount of backflow. This last case applies predominantly to the City's storm water system. Potable water does not outflow to the ocean, and sewage systems are pressurized.

Sewage Systems

Exposure: The sewage systems in Santa Barbara consist of two types: mains and structures. Sewer structures include sewage transport infrastructure that are not the physical pipes. Only three structures would be exposed to permanent inundation with 0.93 m SLR (2100 Medium), whereas 80 structures would be exposed with a 1.67 m SLR (2100 High). **Figure 4.5** shows the exposure of sewer structures to storm surge.

Sewer mains are significantly exposed to permanent inundation, as many of them exist along the coastline. In this context, "exposed" refers to overland flooding or inundation, which could cause buoyancy or other technical engineering problems that are beyond the scope of this report. A significantly larger portion of sewer mains may be vulnerable to overland flooding with a 100-year storm surge (**Figure 4.5a,b**). City data were restricted to some flood-prone portions of the coastal and downtown Santa Barbara area. For this reason, erosion was not included in the analysis, though it can be assumed that sewer lines follow the roads along the bluffs. Additionally, the most extreme flood projections are beyond the boundaries of the clipped data, meaning that the projected flood-prone areas with high levels of sea level rise are underestimates.

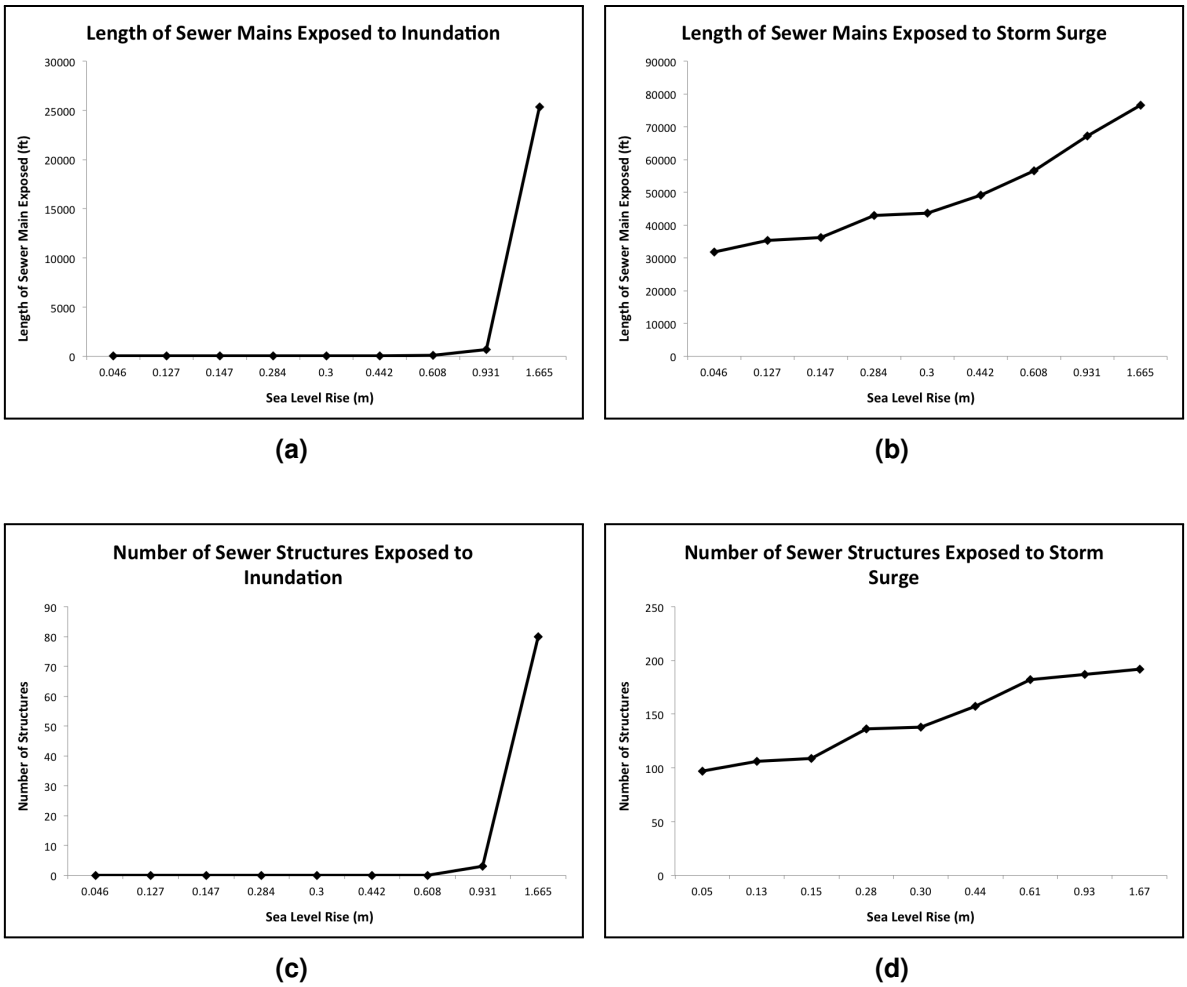


Figure 4.5: Sewer transport systems exposed to inundation and storm surge hazards.

Sensitivity: Sewage infrastructure in Santa Barbara is a high sensitivity resource because if these resources were to fail there could be serious health consequences for the City. Furthermore, the overall functioning of the El Estero Wastewater Treatment Plant, another high sensitivity resource, relies on these sewage structures to maintain its functionality.

Storm Drains

Exposure: Three types of structures that make up storm drains were analyzed: nodes (such as manholes), pipes, and channels. The node at Mission Creek Lagoon has the highest exposure to permanent inundation, as it is the only node that would be exposed by 0.15 m SLR (2030 Medium). Another node located on Shoreline Drive near Santa Barbara Harbor becomes exposed to permanent inundation at 0.28 m SLR (2050 Medium). Once inundation reaches 0.93 m SLR (2100 Medium), 40 nodes become exposed. With 1.67 m SLR (2100 High), there are a total of 290 nodes exposed. The number of nodes exposed to storm surge and erosion is much higher than those exposed to permanent inundation. See **Appendix D** for the total exposure of nodes to storm surge and erosion.

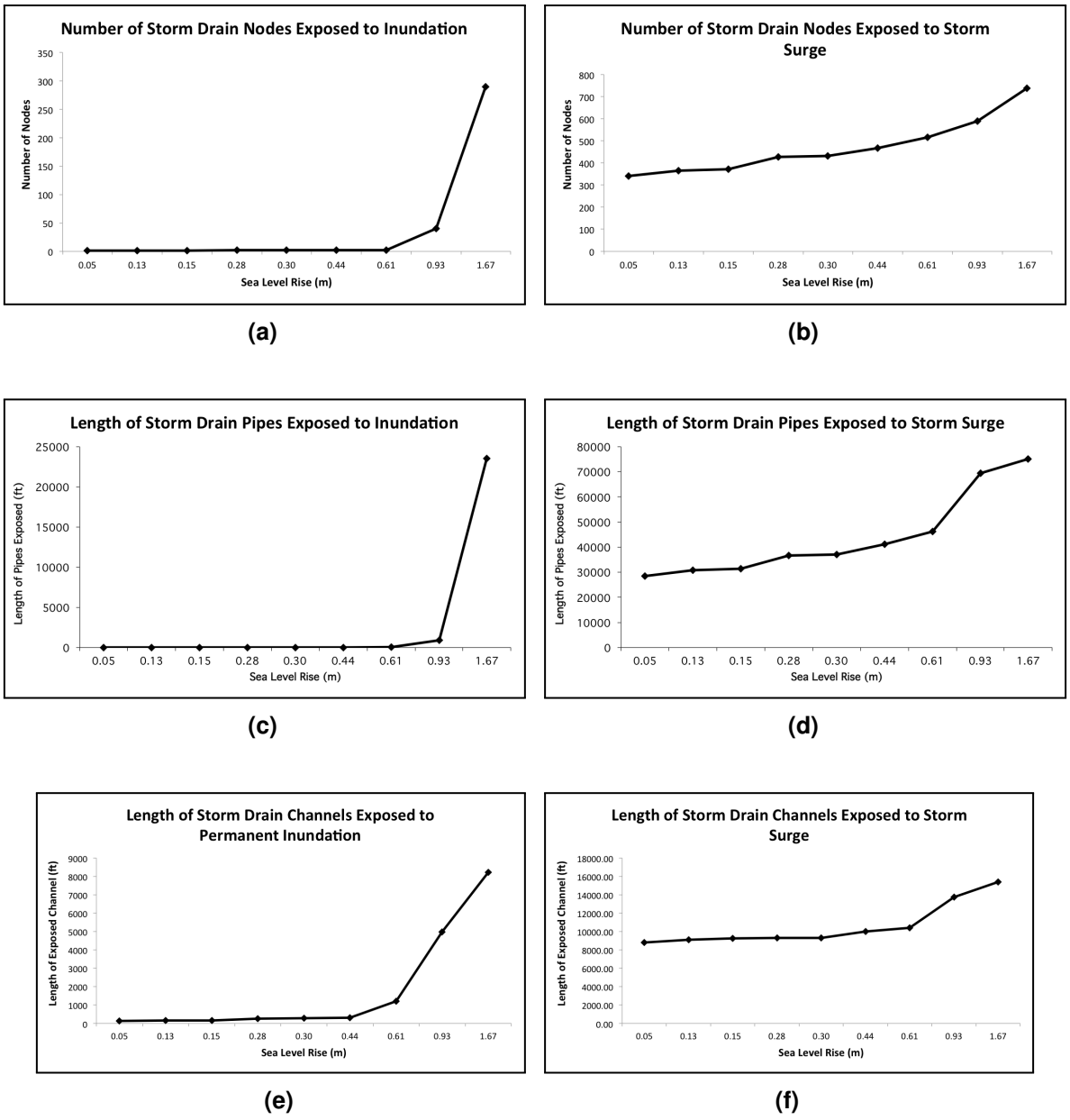


Figure 4.6: Storm drain structures exposed to inundation and storm surge hazards.

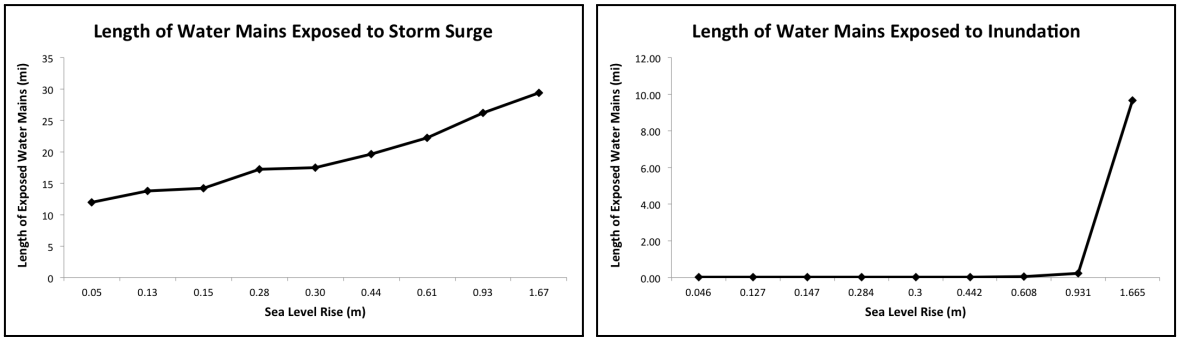
Storm drain pipes are exposed to all levels of permanent inundation, storm surge, and erosion (**Figure 4.6**). Only 20 ft of pipes are exposed to permanent inundation from 0.05 to 0.61 m SLR (2030 Low to 2050 High). Again, at 0.93 m SLR (2100 Medium), a significant increase in the exposure of storm pipes is seen. At this level, over 900 ft of pipes may be exposed and at 1.67 m SLR (2100 High), 23,500 ft would be exposed. Storm channels are also exposed to all levels of permanent inundation, storm surge, and erosion. For information on exposure from storm surge and erosion on drainpipes see **Appendix D**.

Sensitivity: Storm drains are given a high sensitivity ranking because the play a major role in controlling the amount of flooding the City will experience. Storm drains have the capability

to significantly reduce and control flooding and therefore must be maintained. Conversely, if storm drains were to back up completely they could also contribute to localized flooding. Some storm drain outfalls are inundated today under high sea level rise conditions.

Water Delivery Systems

Exposure: The two main water delivery systems analyzed are water mains and fire hydrants. One fire hydrant may be exposed to sea level inundation by 0.93 m SLR (2100 Medium). However, at 1.67 m SLR (2100 High), 61 fire hydrants are within projected inundation hazard zones. A 100-year storm surge exposes an additional 53 fire hydrants to flooding. This is likely an underestimate, as fire hydrant data was also clipped to a smaller geographic area than this project's hazard zones.



(a) **(b)**

Figure 4.7: Water mains exposed to inundation and storm surge hazards.

No fire hydrant locations were included in the erosion hazard zones due to an incomplete dataset for the City. There are also fire hydrants located on Stearns Wharf, which were not included because of a lack of elevation data for Stearns Wharf.

Water mains are exposed to all levels of permanent inundation and storm surge because many of them lead out to the ocean. **Figure 4.7** shows the exposure of water mains to permanent inundation and storm surge. Water mains within the erosion hazard zones were also not included in this dataset.

Sensitivity: Water delivery systems are considered to be a high sensitivity resource because they are essential for both health and safety of the City. In the event of a disaster, fire hydrants are an important resource needed by emergency services and water mains provide potable water to the citizens of the City.

4.2 Human Populations Element

4.2.1 Populations within Permanent Inundation Hazard Zone

Exposure: Analysis of permanent inundation in Santa Barbara for human populations, the results are separated by "low inundation" and "high inundation." Low inundation ranges from 0.05 m SLR (2030 Low) to 0.93 m SLR (2100 Medium). At the block group level, there is no difference in which block groups would be exposed to inundation scenarios between 0.05 and

0.93 m SLR (2030 Low to 2100 Medium). High inundation refers to block groups exposed to 1.67 m SLR (2100 High). **Figure 4.8** shows all block groups within any analyzed hazard zone.

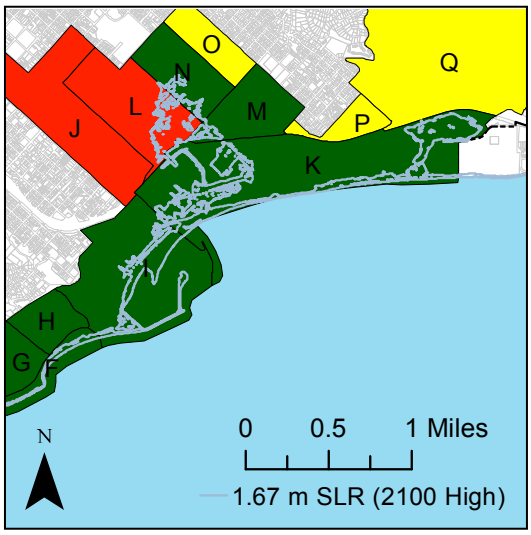


Figure 4.8: Human population sensitivity within inundation hazard zone.

With 0.05 to 0.93 m SLR (2030 Low to 2100 Medium), the total population of the two block groups (I and K) exposed to sea level rise is 857 people. Twenty-one percent of the at risk population are householders who are over 65 years of age, and 47% of the total at-risk population is living alone. Renters account for 78% of the at-risk population, and 37% of households within these block groups have had an income below the poverty level within the past 12 months.

At the highest projected sea level rise value (1.67 m SLR, 2100 High), three additional block groups (L, M, and N) are exposed to inundation, for a total of five block groups. These five block groups (**Figure 4.8**) contain a total population size of 1,401 people. Approximately 38% of the populations affected live in households with one or more persons under 18 years old, while another 36% are living alone. Eighty-six percent of the households within these block groups are renters, and 53% are households that have had an income below the poverty level within the last 12 months.

Sensitivity: Of the five block groups exposed to 1.67 m SLR (2100 High), only block group L has a high sensitivity (**Figure 4.8**). Block group L is the most sensitive block group within any hazard zone. This block group received a score of three for every variable analyzed except for "poor English" or "five or more persons within the household" (U.S. Census Bureau, 2013).

The low sensitivity block groups only have a single instance of one of the categories being in the highest quantile. For instance, this occurs with renter occupied housing in block group I.

4.2.2 Populations within the Storm Surge Hazard Zone

Exposure: For 0.05 to 0.61 m SLR (2030 Low to 2050 High), a 100-year storm surge may flood portions of six block groups, exposing the previous five (I, K, L, M, and N) and one additional block group (Q). These block groups represent a population of 3,029 residents, 77% of which are renters. Fourteen percent of the population does not have access to vehicles. Single parent families comprise 22% of the households. Forty percent of the population is living alone, while only 5% live in houses with five or more people.

A 100-year storm surge combined with 0.93 m SLR (2100 Medium) is projected to affect seven block groups, additionally exposing block group H. These block groups represent a population of 3,459 residents. Approximately 25% of householders are over 65 years of age, and 24% of households contain at least one child under the age of 18. Renters occupy 78% of residences and 20% are single parent households.

A 100-year storm surge coupled with 1.67 m SLR (2100 High) is projected to affect ten block groups (block groups J, O, and P become exposed), and a total of 5,043 people (**Figure 4.9**. Nearly 30% of affected houses have at least one or more person under 18 and 34% of the population lives alone. Seventy-seven percent of the houses are renter occupied, while 52% of the population has poor English ability and single parent households comprise 21% of the affected population.

Sensitivity:

A 100-year storm surge coupled with 0.05 m to 0.61 m SLR (2030 Low to 2050 High) exposes eleven block groups, additionally exposing block group Q. Block Group Q has a medium sensitivity and received the highest scores in the renter, one-person household, and householder over 65 variables.

A 100-year storm surge with 0.93 m SLR (2100 Medium) exposes twelve block groups, including one additional low sensitivity block group (H). There are no variables within block group H that are within the highest quantile of sensitivity.

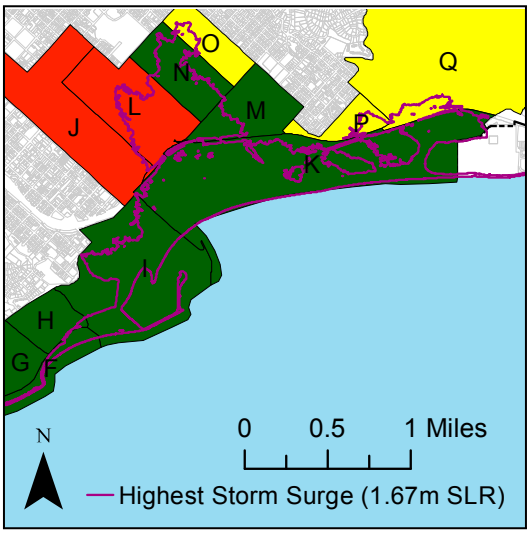


Figure 4.9: Human population sensitivity within storm surge hazard zone.

When a 100-year storm surge is added to 1.67 m SLR (2100 High), three more block groups (J, O, and P) are within the hazard zone for a total of fifteen exposed block groups (**Figure 4.9**). Block group J is high sensitivity and block groups O and P are medium sensitivity. Block group J is within the highest quantile for renter occupation, no vehicle access, and one-person households. Block groups O and P are within the highest quantile for households with five or more people and households with one or more person under 18.

It should be noted that small portions of block groups A and B may also be affected by storm surge. Due to their large size and small fraction of the population living in this low elevation area of Arroyo Burro, those block groups were analyzed in the erosion section.

4.2.3 Populations within the Erosion Hazard Zone

Exposure Hazard: Bluff erosion is and will continue to be a formidable problem for Santa Barbara's population. People living on the Mesa and in the Braemar neighborhoods are the most affected by bluff erosion. Property values along the bluffs are quite high, and the populations include many long-term residents of Santa Barbara. The high-, medium-, and low-hazard areas are calculated from rates of 6, 12, and 24 inches of bluff erosion per year, respectively.

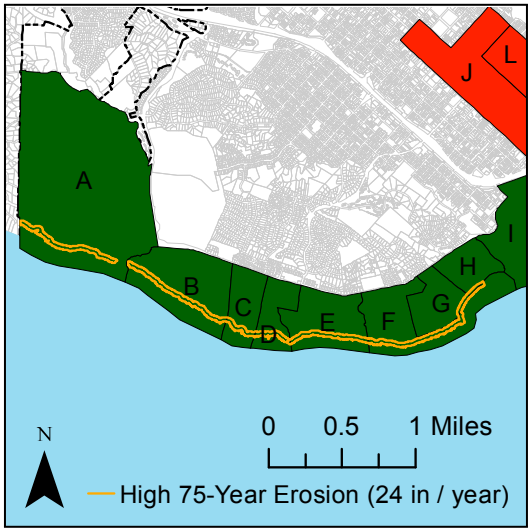


Figure 4.10: Human population sensitivity within erosion hazard zone.

Sensitivity: Eight block groups will be affected in all erosion scenarios considering 75 years of bluff erosion (block groups A-H), which contains a total population of 2,393 people. Householders 65 years or older constitute nearly 33% of householders within these block groups. Thirty-six percent of the total populations in these eight block groups are renting their homes, and less than 1% of the population has poor English abilities or live below the poverty level. All of the block groups that are affected by erosion hazards are low sensitivity. Three of the eight block groups are within the middle quantile for the householder being over 65 years old. These medium quantile scores occur within block groups A, E, and F. The analysis for Census data can be found in **Appendix D**.

4.3 Recreation and Public Access Element

Santa Barbara includes many open spaces along the coast that are vulnerable to sea level rise. Most recreation and public access facilities within the Coastal Zone are adjacent to the water. The highest sensitivity sites are also those most exposed (**Figure 4.11**).

Figure 4.11: Recreation and public access sensitivity within erosion, storm surge, and inundation hazard zones.

4.3.1 Santa Barbara Harbor

Exposure: Santa Barbara Harbor is very exposed to both permanent inundation and storm surge. While the breakwater helps reduce exposure from storm surge, it will not be helpful for the gradual exposure to inundation from sea level rise, and its effectiveness will be reduced as the elevation difference between mean sea level and the top of the breakwater decreases, allowing waves to overtop it more frequently.

The Harbor opening is exposed to storms that originate from the southeast. This allows more wave energy to enter into the Harbor and cause damage to both the infrastructure and boats. Westerly waves with long periods also cause damage. These kinds of waves have the energy to easily overtop the breakwater and inundate infrastructure on the west side of the Harbor, including the Yacht Club parking lot and Harbor Way. Additionally, with an increase in wave and storm activity, the Harbor will see more sand infill at the end of the breakwater extension.

Sensitivity: Santa Barbara Harbor is considered to be high sensitivity, receiving 17 points out of a possible 28 points. Since this site is the only marina within the City of Santa Barbara and is a working harbor, it is one of the most important sites for all ocean-dependent industry and recreation. The Harbor has 1,100 slips, which house both recreational and commercial boats. It is also home to Santa Barbara's Coast Guard station, which is an important safety resource within the area. If the Harbor were inundated or damaged, the City of Santa Barbara's coastal industries such as fishing and tourism would be highly impacted.

4.3.2 Beaches

Arroyo Burro Beach County Park

Exposure: Arroyo Burro Beach has a very high exposure for all three hazards in this analysis. The site is predicted to experience the effects of permanent inundation by 0.05 m SLR (2030 Low), and is already affected by storm surge at that level. This is one of the few beach parks affected by bluff erosion due to its proximity to the Mesa bluffs. Even at a prediction of six inches per year of bluff erosion, Arroyo Burro will likely be affected.

Sensitivity: Arroyo Burro is considered to have a high sensitivity because it contains a large number of recreational attributes. Within the analysis, this site scores an overall 18 out of 28 possible points. This site is very diverse in the amenities it provides its visitors, including restaurants, parking, restrooms, beach showers, and picnic areas including BBQs, which would be negatively affected by inundation, storm surge, and erosion.

Leadbetter Beach

Exposure: Leadbetter Beach is also very exposed to storm surge and inundation. Its low elevation makes it susceptible to even our lowest projection of sea level rise (0.05 m SLR, 2030 Low). For these same reasons, Leadbetter Beach is susceptible to a 100-year storm surge at every level projected. In this analysis, the bluffs just west of the beach up to Santa Barbara Point were considered a part of Leadbetter Beach. This means that this beach area is also susceptible to bluff erosion.

Sensitivity: Leadbetter Beach is one of the most sensitive recreation and public access sites in Santa Barbara. In this analysis, Leadbetter Beach scored 15 points out of 28 possible points.

The primary attributes that make Leadbetter Beach sensitive are the available picnic areas and visitor facilities (for instance restrooms and beach showers). Many of these resources and facilities would be exposed to the effects of sea level rise inundation and storm surges.

East Beach

Exposure: East Beach is also considered to be very exposed, primarily due to its proximity to the ocean and low elevation. Any level of inundation or storm surge would affect East Beach. East Beach is not vulnerable to bluff erosion, though landslide damages at the Clark Estate bluffs could affect the furthest edge of the beach.

Sensitivity: East Beach received 19 points out of a possible 28, the highest number of attributes of any of our recreational sites. East Beach is considered a high sensitivity recreation resource due to the many types of activities that occur there. The most distinctive of its features include volleyball courts, offshore moorings, and the Cabrillo Pavilion and Bathhouse with its parking lots. Since this site includes so many unique attributes, it is considered to be one of the most sensitive areas on the Santa Barbara coastline.

West Beach

Exposure: West Beach, like the other waterfront beaches, is highly exposed to storm surge and inundation because of its low elevation and proximity to the coastline. Even at the lowest projections of sea level rise (0.05 m SLR, 2030 Low), West Beach would be affected by both increased sea levels and a 100-year storm surge.

Sensitivity: West Beach was also ranked as a high sensitivity recreational site based on its numerous amenities. It received a total score of 14 points out of 28, just a few points below East Beach's top score of 25. There are many attributes that West Beach has that are vulnerable to the effects of inundation and storm surge. Some attributes include are the lifeguard stations, restrooms, multi-use beachway, dry storage areas for vessels, and activities like kayaking and swimming in the area.

4.3.3 Stearns Wharf

Exposure: Given its elevation above sea level, Stearns Wharf is not particularly susceptible to inundation, except at its entranceway at Cabrillo Boulevard. Conversely, Stearns Wharf is very exposed to storm surge due to the surrounding ocean. Its exposure is decreased because of its proximity to the Harbor, which deflects most wave and storm energy coming from the west. The Wharf is most exposed to the south and east making it particularly vulnerable to pre-frontal southeast winds and waves. The wharf is also vulnerable to westerly swells with long periods that hold a large amount of wave energy. The coincidence of southeast winds and large westerly swells create conditions most threatening to the wharf structure (K. Treiberg, personal communication).

Stearns Wharf is composed of 2,000 wooden piles, which are vulnerable to the effects of rising sea levels. These piles naturally erode in seawater, which poses a problem with the overall structural integrity of the Wharf. Each year, the City Waterfront Department must replace structural piles in order to maintain a working pier. The businesses that are located on the Wharf already experience the effects of storms and wave action, such as the rogue wave that broke windows at Moby Dick restaurant in 2014. With rising sea levels, incidents like this may

become more common.

Sensitivity: Stearns Wharf is a high sensitivity recreational resource. The Wharf received 15 points out of a possible 28 points. Stearns Wharf is the only functional pier within the County of Santa Barbara, and is a historic structure. The Wharf is an important aspect of the waterfront for the local tourist economy. Furthermore, it is one of the most iconic locations within the City and boasts many important recreational opportunities including fishing, boat tours, and shopping.

4.3.4 Parks

Shoreline Park

Exposure: Shoreline Park itself may be affected by sea level rise due to inundation or storm surge by increased erosion rates. The park is vulnerable to erosion hazards with any projected erosion rate, irrespective of sea level rise, since it is located directly at the edge of a coastal bluff (**Figure 4.12**). Shoreline Park additionally includes a public access staircase to the beach at the base of the park, which is vulnerable to erosion, storm surge, and inundation. A 2008 landslide destroyed a portion of the pedestrian pathway, resulting in the need to set back and reroute the path.

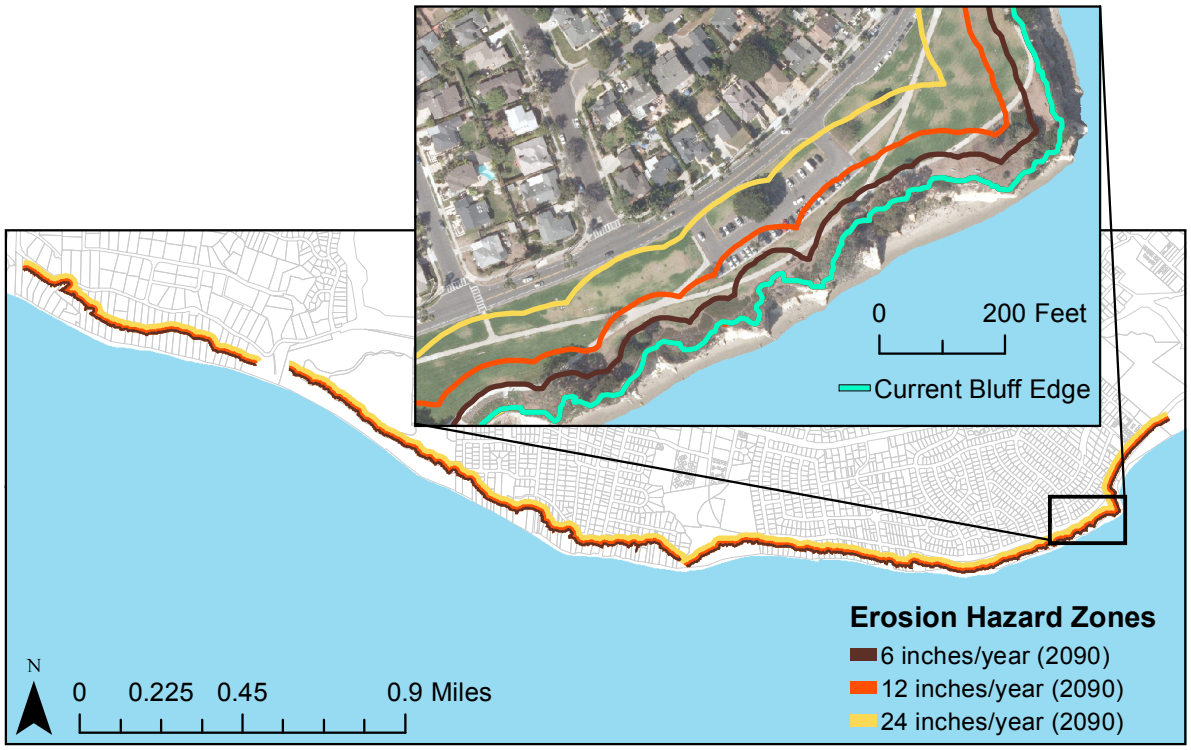


Figure 4.12: Erosion hazard inset map for Shoreline Park.

Sensitivity: Shoreline Park is considered to have a high sensitivity and received 15 points overall. This park has fewer facilities than other areas within Santa Barbara. The park does have some important facilities which could be increasingly threatened by changing conditions. Some of the facilities at Shoreline Park include restrooms, pedestrian walkways, parking lots,

a playground, beach access stairs, picnic areas, and BBQs.

Chase Palm Park

Exposure: Chase Palm Park is a unique site along the Waterfront in Santa Barbara because the park itself straddles both the north and south side of Cabrillo Boulevard. This gives it a varied exposure level to the effects of inundation. Taking only permanent inundation into consideration, the southern portion of Chase Palm Park may be exposed with 0.93 m SLR (2100 Medium), and the northern portion at 1.67 m SLR (2100 High). On the other hand, 100-year storm surge hazards exist in both parts of the park and are projected with the lowest levels of rise (0.05 m SLR, 2030 Low).

Sensitivity: Chase Palm Park is a high sensitivity resource with 16 points. The park offers multiple unique attributes to the downtown waterfront area, including its playground, bike and walking path, restrooms, and visitors center. As the park is threatened by both permanent inundation and a 100-year storm surge, these facilities would be the areas of primary concern.

4.4 Ecological Resources Element

The City of Santa Barbara hosts several important ecological resources that are located along the City's coastline. Wildlife species of concern with Federal or State listings include: the California least tern, western snowy plover, tidewater goby, and southern California steelhead (URS, 2008). Specific wildlife areas were analyzed for their exposure and sensitivity to sea level rise the results of which are outlined below (**Figure 4.13**).

Figure 4.13: Ecological resources sensitivity within erosion, storm surge, and inundation hazard zones.

4.4.1 Santa Barbara Beaches

Exposure

The beaches of Santa Barbara are exposed to inundation and a 100-year storm surge with even the lowest projected sea level rise. The highest sea level rise projection for 2100 (1.67 m) would inundate 76.2 acres. A 100 year storm would affect an additional 38.6 acres located within the hazard zone. Even today, all of Santa Barbara's beaches are vulnerable to storm surge, as evidenced by the recent March 2014 storm and by the El Niño of 1997-98 and the 100-year storms from El Niño storms of 1982-83.

Sensitivity

The beaches of Santa Barbara are considered medium sensitivity due to the existence of endangered and threatened species living, roosting, and nesting on the beaches. The Western Snowy Plover–a federally listed threatened species–has critical habitat designated on the beaches. Mission and Laguna Lagoons are also located on East Beach, but will be addressed within the Creeks section.

4.4.2 Harbor Sandspit

Exposure

The Harbor breakwater creates a 325,000 square foot artificial sandspit at the entrance to the harbor. It is an area that attracts wildlife (primarily seabirds) because of its isolation from humans and its proximity to the channel. This landform is constantly evolving and is currently vulnerable to storms and will continue to be exposed to storm surge with sea level rise. While this study's modeling results indicate permanent inundation of the sandspit with sea level rise, sand from littoral drift will continue to build here until sea level overtops the breakwater extension, at which point sand would fill in the harbor at a faster rate than today.

Sensitivity

In this analysis, the sandspit is considered to have medium sensitivity due to being known as a roosting habitat for the Western Snowy Plover (URS, 2008). However, this resource is unlikely to be affected by permanent inundation unless dredging efforts leave the sandspit unexposed.

4.4.3 Creeks and Wetlands

The creeks and wetlands in Santa Barbara's Coastal Zone include many ecological resources. The City's estuaries in particular are exposed to inundation with as little as 0.05 m SLR (2030 Low). Total area of creeks and wetlands exposed to inundation and storm surge can be viewed in **Appendix D**.

4.4.4 Andrée Clark Bird Refuge

Exposure

Andrée Clark Bird Refuge is an important regional wetland and bird habitat and one of the most popular sites for bird watching in Santa Barbara. It is a brackish lagoon, which does not open to the ocean naturally. In its current state, it is protected from inundation by East Beach and

has a relatively low exposure to sea level rise and storm surge. Only at the highest projection of sea level rise (1.67 m SLR, 2100 High) would Andrée Clark Bird Refuge be inundated. It is, however, affected by storm surge of a large storm even at current sea levels. Higher sea levels will increasingly expose this resource to a 100-year storm.

Sensitivity

The Andrée Clark Bird Refuge was ranked as a high sensitivity resource because it is a designated habitat for the endangered tidewater goby. There are no other endangered or threatened species that reside in Andrée Clark Bird Refuge, but several sensitive species have been observed in the refuge, including the California least tern, and double-crested cormorant.

4.4.5 Creeks

The primary creeks within the City of Santa Barbara are Arroyo Burro Creek, Mission Creek, Laguna Channel, and Sycamore Creek. The data used incorporates Mission Lagoon and Laguna Lagoon into their upstream creeks.

Exposure

Arroyo Burro Creek is the creek most exposed to permanent inundation. This creek would be exposed even at the lowest projection of 0.05 m SLR (2030 Medium). Mission Creek and Laguna Creek are less exposed to inundation given the data used, though this would change if the creeks were managed as open. These creeks would not be exposed to inundation until 0.93 m SLR (2100 Medium), at which point their lagoons may not close. Portions of these creeks are channelized, particularly near the coast, but the City has constructed fish ladders in some creeks to help the southern California steelhead trout species.

Sycamore Creek also flows through the Eastside of Santa Barbara and opens up in the middle of East Beach. This creek is less exposed because it is not expected to experience permanent inundation until 1.67 m SLR (2100 High). Even without any rise in sea levels, all of these creeks are already exposed to storm surge.

Sensitivity

Arroyo Burro Creek, Mission Creek, Laguna Creek, and Sycamore Creek serve as habitats for the tidewater goby, making all three creeks high sensitivity ecological resources. The reproductive cycle of the tidewater goby "requires closed lagoons and a specific range of salinities" (U.S. Fish and Wildlife Service, 2013). As these creek mouths increasingly connect to the ocean, the tidewater goby populations may be threatened.

Mission Creek is also a federally registered critical habitat for the endangered southern California steelhead trout, a genetically unique population of the California steelhead. The brackish Mission Lagoon, located on East Beach, is important for the reproductive cycle of the steelhead trout. The lagoon is within the southernmost range of the California steelhead trout; habitat for the southern steelhead range from Santa Barbara County to Mexico near Baja California (Office of the Federal Register, 2012). Steelheads are an anadromous species and are dependent on the lagoon being opened periodically for the fish to complete their reproduction cycle. Since this creek is home to two different endangered species, it is considered a high sensitivity ecological resource.

5. Discussion

Consistent with recommendations from the CCC Draft Sea Level Rise Guidance Document (2013), the City of Santa Barbara has been preparing site-specific vulnerability assessments for various capital improvement projects, including the Cabrillo Bridge Replacement Project and the Cabrillo Pavilion Arts Center and Bathhouse Renovation Project.

The three major sea level rise adaptation strategies for any resource are: to retreat or relocate, protect in place, or elevate. Ultimately, it will be the responsibility of the City in conjunction with its stakeholders to determine appropriate actions, thresholds, and triggers for implementing these strategies.

5.1 Adaptive Capacity

5.1.1 Critical Infrastructure Element

Transportation

The main adaptation options for transportation structures are: relocating, raising, protecting, or improving drainage (Hille & Paul, 2013). Each option includes costs and tradeoffs with respect to planning and policy, and not all options are feasible or advisable. These measures can be quite costly, site specific, and depend on the expected extent of damage the structure will experience.

For example, the Garden Street underpass has a very low elevation and is projected to act as a hydraulic connection for water to enter the Downtown area. Therefore, in order to protect this high traffic road that provides critical access to Highway 101 and the coast, and potentially alleviate some of the flood risk, raising this road could be a good adaptation option. In the meantime, investing in drainage improvement projects will become increasingly important. Currently, the Laguna Pump Station may be the primary way to stop the Garden Street underpass from flooding. Increasing the capacity of this pump station is an appropriate medium-term goal, to be implemented before 0.93 m SLR (2100 Medium). The combined effects of fluvial and coastal storm flooding create higher risks to this station, so planning efforts should be well on their way by 2050.

An important local and regional transportation facility within the hazard zone is the railroad. The most feasible adaptation option for the railroad may be to raise it to avoid flooding and inundation in low-lying areas. A large structure such as a seawall may protect the railroad at the cost of flooding parks and recreational facilities closer to the ocean. The CCC is unlikely to allow such a seawall under current conditions and as such, early coordination and cooperation with the Union Pacific Railway may result in faster project approval.

Because transportation systems connect Santa Barbara with the rest of California and provide a throughway for California residents and tourists alike, they are considered more critical than Coastal Zone parking lots. However, parking availability is very important to the economic viability of the City. Options facing the City include rebuilding and/or retreating. Relocating parking lots to less hazardous areas could be coupled with increasing public transportation opportunities (shuttles and trolleys) to the coast.

Critical Structures

Critical structures share many of the same adaptation options as transportation structures (retreat, raise, protect), but buildings can also be constructed to withstand higher water levels from flooding. Flood protection measures include raising entryways, waterproofing foundations and utilities, and redirecting storm water flow. The City should consider prioritizing structures for additional flood proofing by their critical function, their exposure to current fluvial flooding and future coastal flooding potential.

Similarly, resiliency plans should be considered for the El Estero Wastewater Treatment Plant and other highly critical structures. Creating clear planning strategies if sea level rise threatens to increase backflow conditions will be necessary before the threshold of 0.93 m SLR (2100 Medium). Additional water-diversion or flood-proofing methods may be especially important for the inflow pipe and pump area, located in a building well below current sea level. El Estero Wastewater Treatment Plant is also a very developed and valuable resource containing 16 total structures that are valued at approximately $11.3 Million in 2011 dollars (Santa Barbara County Office of Emergency Management, 2011). Therefore it may be most cost effective to implement a protection structure or flood proof the buildings. Similarly, Charles Meyer Desalination Plant, although not currently in use, contains expensive infrastructure and may be a strong candidate for flood proofing or protection when the City reactivates this plant. Because both El Estero Wastewater Treatment Plant and Charles Meyer Desalination Plant are located in the Industrial Component of the Coastal Zone, a large protection structure could be an appropriate option for adaptation of these resources (see **Appendix E** for maps of resources by Component Areas). This is because the area contains few residential populations, ecological resources, or recreational opportunities.

Lower sensitivity structures such as the Public Works yards and City department buildings do not contain as much immobile and expensive infrastructure. Therefore, these structures are ideal candidates for flood proofing measures. However, the historic value of buildings should also be taken into account when deciding on the appropriate adaptation strategy.

Water Transportation Systems

Water transportation infrastructure is beyond the level of expertise of this study for recommending adaptation options. However, pipes may be at risk from hydrostatic, hydrodynamic, and buoyant forces due to inundation or flooding (FEMA, 1999). Inundation is a slower process and water supply pipes at the coastline can be turned off permanently as sea level gets too high. During storm events, with proper forewarning and monitoring, water mains can be shut off to reduce the risk of damage. At the policy level, encouraging protection measures of various in-home utility systems can greatly decrease the likelihood of expensive damages within buildings. Where these facilities are exposed to erosion hazards, the City may want to consider developing methods to improve response times to water main breaks along the bluffs in order to decrease bluff oversaturation.

Overall, adaptation for critical infrastructure is most effective by assessing site-specific needs. Strategic planning over time will allow the City to identify the structures that are most affected by inundation, storm surge, and erosion in order to apply appropriate adaptation measures as more information regarding current an future sea level rise rates become available for Santa Barbara.

5.1.2 Human Populations Element

Inundation and Storm Surge

While the vulnerability of populations to sea level rise is low within the Coastal Zone, continuing to promote hazard awareness and preparedness within communities is important. Supporting community-building and neighborhood events is one important way to increase the City's post-disaster resiliency (Ekstrom & Moser, 2013).

One proven method to increase adaptive capacity is to have periodic and meaningful public engagement. The City currently has a few programs in place for community member disaster preparedness, notably the Community Emergency Response Training (CERT) through the City's Fire Department as well as community-based partnerships for disaster management scenarios (Santa Barbara County Fire Department, 2015). Continuing to increase communication and information exchange will aid in the development of adaptation goals for the community.

High sensitivity areas are at relatively low risks to permanent inundation, but are in low-lying areas vulnerable to flooding, while low sensitivity areas have in areas of higher inundation exposure. The City may consider expanding flood proofing requirements for designated Special Flood Hazard Zone to include projected 100-year storm flooding zones for a given design lifetime of a structure. The LCP covers only the Coastal Zone, but could provide a policy basis for increased housing stock resiliency.

Bluff Erosion

All block groups that are within the erosion hazard zones are considered to be low sensitivity. A moderate number of elderly and children live on the bluffs, but housing density is quite low and homeowners' financial abilities to respond to a landslide disaster are high. Continually updating the erosion hazard line to be current with bluff edges will keep setback areas from becoming outdated. A methodology to quickly incorporate changes in building permits that incorporate these new bluff edges may be valuable to the City. The City can also consider expanding bluff erosion hazard zones to include geology-specific landslide risks. For example, the bluffs between the western City limits and El Camino de La Luz are at higher risk of large bluff failures. (D. Revell, personal communication, February 10, 2015).

Human populations within Santa Barbara are at a relatively low risk to the effects of permanent inundation. The highest risk to populations is bluff erosion, which is a historic problem for populations on the Mesa. Since a number of properties already lie within erosion hazard zones, adaptation strategies will protect future populations from hazards, but may not protect populations living within hazard zones today. It will be important to strengthen conversations with communities and integrate them into planning for emergency situations.

5.1.3 Recreation and Public Access Element

Santa Barbara Harbor

The Harbor's resiliency increased in 2012, when the Waterfront completed a project that reinforced and elevated the breakwater to comply with City code. Currently, the breakwater is 4.9 m above NAVD88 (3.3 m above mean higher high water–almost 11 feet). While waves

overtopping the breakwater are still common, the amount of wave energy that gets into the harbor is currently much less than it would be otherwise.

Dredging activities have not changed significantly in recent years, and the Harbor is annually dredged of about 300,000 cubic yards to keep the Harbor open for boat traffic. The Harbor's adaptive capacity is bolstered due to the presence of a dredge currently owned by contracting company AIS. Various problems could arise from this arrangement, such as decreased federal budgets that only support dredging a portion of the annual average, or delays in negotiations between the U.S. Army Corps of Engineers and possible contractors. A feasibility study of buying a dredge was conducted in 1993. While it was not deemed feasible at the time, it is recommended that the City further consider this option before a half-meter of sea level rise (between 2050 and 2100). City or joint regional ownership of a dredge will allow increased availability and reliability for dredge timing, and may increase the City's ability to complete emergency beach replenishment activities for the City itself and for sand-deprived beaches in the region such as Goleta Beach.

Today, berms are used to protect beachside infrastructure near the Harbor. The primary berm that is protecting Harbor facilities is a seasonally constructed berm built each winter at Leadbetter Beach in front of the Santa Barbara Yacht Club. A limiting factor with utilizing berms is that they may only withstand one major storm. Once a constructed berm is eroded, it must be re-constructed by pumping below-tidal sand onto the upland portion of the beach. Another strategy in place at the Harbor involves the use of sandbags to protect coastal flooding from reaching high priority areas like the Yacht Club and other businesses. Sandbags are a relatively cheap method for protecting coastal infrastructure but they are only a seasonal solution for coastal inundation.

One of the most important adaptations for the City and Waterfront Department to consider is to cap and raise the breakwater extension. This will increase the elevation of the extension and allow for less wave energy to get into the Harbor from that direction, even with increasing sea levels.

Stearns Wharf

The Wharf is considered to have moderate adaptive capacity for similar reasons to the Harbor. Sea level rise and storm activity are factors that the Wharf already faces today. Stearns Wharf is maintained annually as the Waterfront Department replaces small amounts of pilings and beams to ensure structural integrity. In the future, Stearns Wharf can be raised to keep wave damage and temporary flooding from causing damage to life and property on the Wharf. Increasing elevation would most likely happen over time and in segments. As sections of piles are replaced, piles would need to be driven with a higher final elevation. One problem associated with this method is that new piles can't be driven underneath constructed structures without significant deconstruction of the structures themselves. It would be a tricky operation to attempt to balance risk, project approval, and recreation in a major project such as this. The City could consider making these improvements one structure at a time as the facility's lease ends.

Beaches

Nearly all of the City's beaches are significantly altered by humans, making adaptation recommendations more nuanced and challenging because these beaches do not operate in the same as way as natural systems. While it is anticipated that continued dredging would protect East and West Beaches for quite some time, the fixed wall structures at Cabrillo Boulevard and one buried underneath East Beach in front of the Bathhouse need further analysis to determine their future function in relation to infrastructure protection and impacts to beach widths. To allow East and West Beaches to naturally migrate inland, the bike path could be designated as a temporary structure that could be rebuilt after a major storm. Alternatively or additionally, a seasonal berm could be constructed to protect much of the bike path and nearby infrastructure. The volleyball nets on both of these beaches are also a concern in terms of inundation and storm surge. These nets have relatively low costs and simple rebuilding techniques. As beaches narrow, it may be prudent to relocate some of the nets further up the beach profile.

Leadbetter Beach is a slightly different scenario. This area includes a restaurant facility, restrooms with beach showers, and a parking lot. Locals frequent this beach for surfing, and beach activities. An option for this site would be to allow the beach to retreat naturally, which would eventually affect the park recreation area at the back of the beach. At a certain point, however, the beach will abut Cabrillo Boulevard, which would stop the ability for the beach to migrate unless that street was moved further inland or abandoned. Berm construction could be utilized for protection of the park, parking lots, and cafe but the berm would effectively change the visual access from the park and parking lot, and would not serve long-term protective measures.

If the City hopes to maintain the use of these facilities, then it would be important for the facilities to be fortified. If the City is more focused on maintaining the public access site and beach ecosystem, then strategically moving these facilities away from the ocean would be beneficial to allow natural migration of the beach ecosystem.

Parks

Santa Barbara's coastal parks include Shoreline and Chase Palm Park as well as Leadbetter Beach Park and East Beach Park. Shoreline Park is one of the primary bluff top parks within the City of Santa Barbara, and is very vulnerable to erosion. The most effective adaptation strategy for this park is through managed retreat. Bluff erosion at Shoreline Park cannot be avoided. While the City can work to limit its water expenditure to keep the park green, Shoreline Park is at the bottom of a highly urbanized watershed and therefore direct water use is a small overall contributor to increased park vulnerability. Maintaining fence setbacks will decrease risk of public injury during a landslide, and facilities can be relocated landward as the bluff edge retreats.

The Mesa residential community surrounds Shoreline Park. Community development and education will also be beneficial for reducing the rate of bluff erosion. Continuing to educate communities regarding the increased erosion hazards from excess watering and invasive bluff top species such as ice plant is advised. Another adaptation method would be to fortify the stairway access point at Shoreline Park. With inundation and storm surge, the stairs will be vulnerable to becoming structurally unsound. It would be important for the City to continue

monitoring the stairs in order to determine if and when the stairs should be reconstructed or moved.

Chase Palm Park is a complicated site, due its location on both sides of Cabrillo Boulevard. The southern parts of Chase Palm Park are more vulnerable to inundation and storm surge, due to its proximity to the beach. The facilities on the North side of Cabrillo are much less vulnerable to inundation, but will need to be protected from storm surge as sea levels rise. The southern parts of the park abuts East Beach and may need to be removed to allow East Beach to retreat naturally over time if the beach is valued over the park. In order for this to occur, the bike path that runs on the south side of Chase Palm Park would need to be moved landward.

If it were important to the City to maintain the park instead of the beach, construction of a berm or seawall would help protect the park from inundation and storm surge. Construction of seawall would have a negative impact on East Beach over time and cause the beach to erode and narrow over time if dredging does not make up for the increased sea levels.

Overall, adaptation of recreation and public access sites is dependent on the specific values that the City holds. It will be important for the planning department to indicate which structures and areas are the most important for recreation and public access in the area. Once these positions are decided upon, the City can determine which facilities and activities are most important to protect.

5.1.4 Ecological Resources Element

Beaches

Beaches are vulnerable to a host of drivers, such as sea level rise, large storms, and coastal armoring. Natural beaches would migrate landward with rising sea levels to maintain the structure and function of the beach. In Santa Barbara, however, the downtown beaches are not in their natural state. The combination of sand nourishment from dredging, and the existence of a low seawall along Cabrillo Boulevard reduces the adaptive capacity of our beaches. Because these man-made processes have been conducted for so long, it is difficult to know how these beaches would act in their natural state.

The primary adaptive capacity option regarding beaches is to allow for inland migration. This would require movement of all beachside structures to allow for natural processes to take control of the beach location. Because the changes to this non-natural system are unknown, beach monitoring should be prioritized. The Waterfront Department commissions at least one aerial image a year to monitor the coast of Santa Barbara. Additional funds could be set aside to take a minimum of two aerial photos per year. Similarly, it would be important to photograph the coast immediately after a large storm and and another a few months later to determine how the City's beaches respond to and recover from storm events. Protecting the habitat of threatened species like the western snowy plover on East Beach will be particularly challenging as land uses and protection laws compete.

Harbor Sandspit

The Harbor sandspit is a unique ecological resource within the City of Santa Barbara that results entirely from the disrupted littoral drift along the coastline. As long as the Harbor breakwater and extension are intact and above water, it is unlikely that this habitat will

disappear due to sea level rise. It is fairly vulnerable to storm surge, but as long as sand flow is still occurring after the storm, the berm will be naturally built up again over time.

Andrée Clark Bird Refuge

Andrée Clark Bird Refuge is susceptible to saltwater intrusion. The ecosystem itself is adapted to low levels of salt concentrations, but would be severely damaged if the lagoon saw a significant rise in salt concentrations. This wetland is one of the last wetlands in downtown Santa Barbara, and is therefore recreationally and ecologically important. Landward migration is also a primary adaptation mechanism that coastal wetlands utilize to react to sea level rise. If the City considers the refuge to be of importance, it will be pivotal for the City to ensure that the wetland has room to expand inland. This could be done by easements on proximate property, or restoration of nearby parks into ecosystems that could be turned into wetlands over time.

Creeks

Santa Barbara's natural coastal creeks–Arroyo Burro, Mission, and Sycamore–are all tidewater goby habitat, with Mission Creek additionally considered important for steelhead habitat. Increased inundation of these habitats will change water composition and, if possible, may force species to move further inland. Restoring habitat will be of heightened importance in the future. The City should ensure that current restoration project plans are creating appropriate habitats for the species of importance. Laguna Channel is similar in its capacity to respond to rising sea levels, but has become channelized within the Coastal Zone, making its sensitive habitat predominantly on the beach within the Lagoon.

Overall, Santa Barbara's ecosystems are home to many federally listed endangered and threatened species. Because of this, it is important that the City maintain the functioning of these ecosystems to support these species. Adaptation for ecosystems is primarily inland migration to suitable habitat, and as such the City may need to create suitable habitat in other locations for these species.

5.2 Limitations and Future Work

5.2.1 Exposure Analysis Limitations

This report was designed to be a more complete analysis than the previous sea level rise vulnerability study performed by Gary Griggs and Nicole Russell (2012). Limitations in spatial sea level rise hazard modeling resulted from a lack of wave-climate models currently available for Santa Barbara area, and lack of long-term tide gauge data. Existing structures were not included (except for one scenario analysis) due to a lack of time and data that could easily be integrated with a Bare-Earth Digital Elevation Model. Our results indicate the necessity for continued investments in the upkeep of existing flood protection measures by illustrating the potential hazards without these measures with the addition of sea level rise.

A small and basic scenario analysis was conducted for illustration purposes to show the benefits and potential limitations of some protective infrastructure. A rough elevation of the Laguna Tidegate was integrated into the LiDAR model. With a functional tide gate, Laguna Channel is not expected to become inundated with 0.93 m SLR (2100 Medium).

However, many of the same areas are still projected to be affected by a 100-year storm surge with even the smallest level of projected sea level rise (0.05 m, 2030 Low). This scenario illustrates a relatively straightforward way to further modify the "bathtub" model for increasingly coastal-specific results. While the analysis conducted in this study is not as comprehensive as the modeling currently in progress by ESA PWA for the County's vulnerability assessment (funded by a Coastal Conservancy Climate Ready Grant), it provides a simple way to determine hazard zones for any given sea level rise value. Updated sea level rise projections could quickly be analyzed for significant differences.

Monetary Valuation

Economically valuing storm damage costs, potential damages, and adaptation strategy costs may help the City to identify, which adaptation strategies they wish to employ. These economic considerations were beyond the scope of this study. Fluvial studies and engineering-level assessments of critical infrastructure and flood control mechanisms were also beyond the scope of this group project report.

5.2.2 Sensitivity

There are many aspects of this sensitivity analysis that may be improved with more detailed data and with further guidance on what the City weights as most important.

Critical Infrastructure

The critical infrastructure sensitivity analysis was based on a qualitative valuation that applied an overarching rank to all resources within a particular variable. With a finer-scale analysis, there may be the option to prioritize specific aspects of critical infrastructure as more important than the overarching category. For example, individual roads could be designated as low, medium, and high sensitivity transportation corridors. Major roads that are required for evacuation purposes would be the only ones to receive the high sensitivity rank.

Similarly, some important critical infrastructures that were absent from this group project analysis. In particular, an investigation Santa Barbara's electrical supply would be important to determine the City's resilience to coastal storms. Coastal power plants may be affected by large regional storms and in turn affect the City's supply of electricity. Prolonged lack of electricity may result in failures to many critical infrastructure assets. For example, the failure of the Laguna pump station would result in major flooding to the low-lying underpasses under highway 101. Other utilities were also not included due to a lack of readily available data.

Human Populations

Human populations were ranked across the entire City at the block group level. A more focused analysis of the Coastal Zone could fill in data gaps at or near the parcel level in order to address some of the specific vulnerabilities within the Coastal Zone. Confidential data at the City-level could help guide policy towards protecting areas at the most risk.

Recreation and Public Access

Recreation and public access was ranked using a simple point-based system. By gaining further insight into what both the citizens and the governments of Santa Barbara weight as

important assets or categories of Recreation and Public Access, future assessments can more accurately measure the wants and needs of the City.

Ecological Resources

The ecological resources analysis included limited species-level data, which evaluated primarily federally endangered and threatened species and their habitats. Because of a lack of comprehensive data, this group project study primarily focused on these species. There are multiple other factors that could be incorporated into further study. For example, ecosystem-services and climate change are not included within this analysis, but are important to consider before choosing an adaptation strategy. With these factors incorporated into future study, the city can incorporate policies that address future changes to both ecosystems and species of value.

6. Conclusion

Southern California has fortunately experienced only a slight elevation in sea levels in the recent past, but this trend may increase soon. Even so, this analysis does not project significant permanent inundation until roughly one meter of sea level rise in the last few decades of the 21st century. However, during a major storm enhanced by sea level rise, the effects of flooding could reach as far inland as Figueroa Street. Storm damage is a much greater problem for the City than sea level rise alone, especially given that coastal storms most frequently occur alongside heavy rainfall. With adequate storm water management, these quick and temporary flood risks may be alleviated. Similarly, bluff erosion is a hazard that is projected to increase with sea level rise, mostly affecting homeowners and residents living along the Mesa bluff edge. Tasked with protecting the health and welfare of its citizens, the City should continue to address this hazard and consider incorporating some degree of projections of increased bluff erosion due to sea level rise into their planning policies.

The analysis methodology was also developed with the goal of incorporating new data as it becomes available. The group merged the methods from various studies and created some others in ways that are replicable and available to the City for future use.

Recreation and public access features appear to be most at risk in regards to climate-related sea level rise hazards. To address these risks in a cost-effective manner, City will need to work with the community to prioritize waterfront recreational features. For example, Cabrillo Boulevard is one of the primary barriers of inland beach retreat. By removing or relocating this thoroughfare, Santa Barbara beaches may have the capacity to adapt to rising sea levels and remain a major asset to the city. However, this street is a major transportation corridor for coastal access and is also of historical significance.

While this study followed the CCC's guidelines, future research could address some of the data and information gaps that we encountered during this group project analysis. Developing more robust exposure models would improve this vulnerability assessment; For example, the models from this group project assessment do not account for fluvial flooding, sand transport, or the presence of building structures. Other concurrent studies, like those being done for the County of Santa Barbara, include more detailed modeling work that could more accurately capture the projected impacts of sea level rise. Although the modeling in this simplified study is less robust, it valuable as a simplified methodology for assessing sea level rise hazards as new projections become available.

Quantifying risk of loss of life, property value, or recreational value is another dimension of future risks that were not included within the scope of this study. Using economic information to conduct a cost-benefit analysis would be an important next step for the City to compare adaptation options. Additionally a study of health related impacts of sea level rise would provide greater insight into true future risks of climate change.

Policies to protect Santa Barbara's tide gauge should continue, and the City should consider strategies to make the gauge more dependable. The City's tide gauge, previously located at the end of Stearns Wharf and now located on the City Pier within the Harbor, has only recorded 17 years of disrupted data. Continued data collection will be crucial in realizing the true rate of relative sea level rise giving more accurate future projections.

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Appendices

A Definitions

Table A.1: List of definitions.

Word	Definition
Adaptive Capacity	The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities. (IPCC, 2012, p. 556)
Downscaling	Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses. (IPCC, 2012, p. 558)
El Niño-Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of 2 to about 7 years, is collectively known as the El Niño-Southern Oscillation. It is often measured by the surface pressure anomaly difference between Darwin and Tahiti and the sea surface temperatures in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea surface temperatures warm, further weakening the trade winds. This event has a great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña. (IPCC, 2012, p. 559)
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected. (IPCC, 2012, p. 559)
Hazard	The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. (IPCC, 2012, p. 560)
Lidar	A remote-sensing technique that uses laser pulses to measure distance from the earth. This technology is used to generate high-resolution topographic data, which can then be used to generate digital elevation models for geographic information systems (NOAA, 2015b).

Mean sea level	Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides. (IPCC, 2012, p. 561)
Mean Higher High Water (MHHW)	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch (NOAA, 2013).
Projection	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty. (IPCC, 2012, p. 562)
Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. (IPCC, 2012, p. 563)
Return period	An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity. (IPCC, 2012, p. 562)
Sea level change	Changes in sea level, globally or locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass and distribution of water and land ice, (iii) changes in water density, and (iv) changes in ocean circulation. Sea level changes induced by changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric. (IPCC, 2012, p. 563)
Storm surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. (IPCC, 2012, p. 562)
Vulnerability	The propensity or predisposition to be adversely affected. (IPCC, 2012, p. 564)

B IPCC Emissions Scenarios

The IPCC Fourth Assessment Report projected global sea levels over the next 100 years based on 6 families of emission scenarios described in (IPCC, 2007). The A1 scenario family assumes high economic growth, low population growth that peaks mid century, and the rapid introduction of more efficient technologies. Within this family are scenarios designated as A1FI (fossil fuel intensive), A1B (balanced fuel), and A1T (predominantly nonfossil fuels). The A2 scenario family assumes slower economic growth and technological change, but high population growth. The B1 scenario family assumes the same low population growth as the A1 scenarios, but a shift toward a lower-emission service and information economy and cleaner technologies. Finally, the B2 scenario family assumes moderate population growth, intermediate economic growth, and slower and more diverse technological change than in the B1 and A1 scenarios. The A1FI scenario yields the highest carbon dioxide (CO_2) emissions by 2100, and the B1 scenario yields the lowest CO_2 emissions (NRC, 2012).

C Methods Appendices

C.1 Critical Infrastructure

Table C.2: Critical infrastructure facilities used in analysis.

Resource	Rank
Santa Barbara Fire Station 1	High
Santa Barbara Fire Station 2	High
Santa Barbara Fire Station 6	High
El Estero Wastewater Treatment Plant	High
Charles Meyer Desalination Plant	High
US Coast Guard	High
City of Santa Barbara Police Department	High
Santa Barbara Cottage Hospital	High
Laguna Channel Tide Gate and Pump Station	High
Santa Barbara City Hall	Medium
Ortega Groundwater Treatment Plant	Medium
City of Santa Barbara Public Works Yards	Medium
Carrillo Recreation Center	Low
City of Santa Barbara Department of Parks and Recreation	Low
City of Santa Barbara Departments of Planning and Public Works	Low
National Park Service	Low
Santa Barbara Waterfront Department	Low
Santa Barbara News Press	Low

C.2 Human Populations

C.2.1 American Community Survey and Census Information

Prior to 2005, the United States Census utilized both a short form and a long form version of the census. In 2005 however, the ACS was established to try to streamline the Census process by eliminating the different versions of the census. Today's census constitutes only the short form and is collected once every 10 years. The ACS consists of the "ĂIJlong form" survey and is collected continuously, via randomized samples of populations. These samples are compiled and projected to their communities. The ACS provides estimation projections in 1-year, 3-year, and 5-year intervals. Each projection is utilized for different purposes, but the five-year projection is considered to be the most accurate as it contains the highest number of surveys. The data that was utilized for this study was the 2013 5-year projections. This was chosen because it is the most recent as well as the most accurate.

The Census is collected once every ten years, and is supposed to be a count of the population for zoning, and redistricting. The ACS, on the other hand, targets the characteristics of populations, like vehicle access and income. Since both of these data were recorded at different times and with different methodologies, analyses occurred separately so as not to affect our results.

C.2.2 Variables Justification

Over 65 – These populations may be less or unable to evacuate in a timely manor in the face of a hazard. Similarly, they may be less capable of repairing damages to their residences without help.

Under 18 – Minors may be less able to be independent in the face of a hazard. They do not generally have their own income and rely on others to help them in times of need.

Single Parent – Single parents may be less able to respond to hazards, as they are most likely receiving help from others for childcare and rearing. Their financial income may also not allow them to prepare for hazards as well as dual parent families.

Under Poverty Level – Persons living under the poverty level will be less likely to prepare for a hazard, such as implement waterproofing to their housing, or purchase extra supplies for an emergency.

Renting – Renters have less invested in their housing structures, and may be unable to implement hazard-protecting strategies, such as flood proofing, without owner consent. As such, they are dependent on the owner of the residence for these measures, and may be unable prepare for these problems.

High Density – High density living situations may be more chaotic and difficult to

Living Alone – Citizens living alone may be less able to prepare for emergencies, possibly due to lack of contact with others. In the event of a hazard, these populations may need help from others in order to evacuate, and may be left behind if they do not have a good network community.

Non-English – Non-English speaking citizens will not be able to understand the emergency messages, and may be unprepared for a hazard situation. These populations may also have difficulty with understanding instructions from security personnel who attempt to assist them.

Institutionalized – These populations will require significant amounts of help to evacuate in the event of a hazard. Because of this, they draw resources away from other parts of the City in a time of need.

No Vehicle – The lack of access to a vehicle makes people more vulnerable to hazards because they are unable to transport themselves to a separate location in the event of a hazard. Without this independence, it will be hard for these populations to prepare for an emergency situation.

C.2.3 Margin of Error

Table C.3: Margin of error for ACS block group variables.

Variables	City Totals	Margin of Error	Standard Deviation
Total Population	41,031	97.3	25.7
Householders Over 65	10,532	126.8	43.4
Households with Members Under 18	10,896	68.1	29.8
Householder Living Alone	12,759	76.9	37.8
Living in Household with 5+ people	3,594	115.7	48.5
Renter Occupied Housing	22,171	77.2	34.5
Households with No Vehicle Access	3,540	43.1	23.7
Non-English Speaking Households	9,177	393.6	148.1
Living Below the Poverty Level	1,788	29.2	22.7
Single Parent Households	23,751	69.7	36.3

C.3 Comparison of Demographic Variables

Table C.4: Demographic variables of interest: ACS and Census comparison.

Variable	ACS (2008-2012)	Decennial Census (2010)
1 Person Household	x	x
5 or More Person Household	x	x
Households with 1 or More Persons under 18	x	x
Householder Over 65	x	x
No Vehicle	x	
Households with Income under the Poverty Level	x	
Poor English	x	
Renter Occupied Households	x	x
Single Parents	x	x
Institutionalized Populations		x

C.4 Recreation and Public Access Variables

Table C.5: Recreation and public access variables used.

Public Access and Recreation Variables Used
Parking Available
Accessible by Public Transit
Disabled Access Available
Restrooms Available
Visitors' Center Present
Lifeguard Stands Present
Beach Showers Available
Potable Water Present
Picnic Areas Present
Firepits or Barbecue Areas Present
Mooring or Marina Slips Present
Pier Present
Historic Structure(s) Present
Sandy Beaches Present
Urban Waterfront Present
Stairs to the Beach Present
Pathway to the Beach Present
Blufftop Park Present
Bike Path Present
Wildlife Viewing
Swimming Pool
Swimming, Diving, Snorkeling, Kayaking, or Surfing
Volleyball, Windsurfing or Kiteboarding, Fishing, Boating, or Boat Tours

D Results Appendices

D.1 Critical Infrastructure

D.1.1 Transportation

Table D.6: Roads exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Length exposed to inundation (mi)	Length exposed to 100-year storm (mi)
0.05	Low	2030	0.00	5.94
0.13	Low	2050	0.00	6.84
0.15	Medium	2030	0.00	7.15
0.28	Medium	2050	0.00	8.84
0.3	High	2030	0.00	8.97
0.44	Low	2100	0.00	10.15
0.61	High	2050	0.00	11.34
0.93	Medium	2100	0.04	13.87
1.67	High	2100	4.61	19.88

Table D.7: Length of railroad exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Railroad exposed to inundation (mi)	Railroad exposed to 100-year storm (mi)
0.05	Low	2030	0	3.23
0.13	Low	2050	0	3.26
0.15	Medium	2030	0	3.49
0.28	Medium	2050	0	4.00
0.3	High	2030	0	4.06
0.44	Low	2100	0	4.40
0.61	High	2050	0	4.75
0.93	Medium	2100	0.04	5.22
1.67	High	2100	2.9	6.97

Table D.8: Length of bikepaths exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Bikepaths exposed to inundation (mi)	Bikepaths exposed to 100-year storm (mi)
0.05	Low	2030	0	5.17
0.13	Low	2050	0	6.08
0.15	Medium	2030	0	6.27
0.28	Medium	2050	0	8.20
0.3	High	2030	0	8.32
0.44	Low	2100	0	9.48
0.61	High	2050	0	10.21
0.93	Medium	2100	0.24	11.95
1.67	High	2100	4.2	14.10

D.1.2 Low Sensitivity Critical Structures

Santa Barbara Waterfront Department

Exposure: The Santa Barbara Waterfront Department is comprised of one structure and is exposed to permanent inundation from a 1.67 m sea level rise.

Sensitivity: This analysis ranks the Santa Barbara Waterfront department as a low sensitivity resource because staff can easily be relocated to another location to conduct business. This resources ties into the functioning of the Harbor overall, however, which is considered a highly sensitive resource. See Recreation and Public Access Results below.

City of Santa Barbara Parks and Recreation Department

Exposure: The City of Santa Barbara Parks and Recreation Department consists of 4 structures, three of which are currently exposed to storm surge, and all structures are exposed to storm surge with 0.13 m of SLR.

Sensitivity: The City of Santa Barbara Parks and Recreation Department is also ranked as low sensitivity because essential staff and operations can be relocated to another location easily.

National Park Service Office

Exposure: The National Park Service Office resides within 1 large structure at the Harbor and is exposed to permanent inundation at 1.67 m SLR (2100 high projection). This building is exposed to storm surge at the lowest projection for 2030 of 0.05 m SLR.

Sensitivity: The National Park Service Office is a low sensitivity structure because the business conducted there can be relocated easily. It should be noted, however, that this building also contains numerous resources including many of which are businesses and restaurants that support recreation at the Harbor.

City of Santa Barbara Community Development Department

Exposure: The City of Santa Barbara Community Development Department consists of two structures that are both exposed to a storm surge with 0.61 m of sea level rise.

Sensitivity: The City of Santa Barbara Community Development Department is also ranked as low sensitivity because essential staff and operations can be relocated to another location if the buildings are damaged.

D.1.3 Water Transport Systems

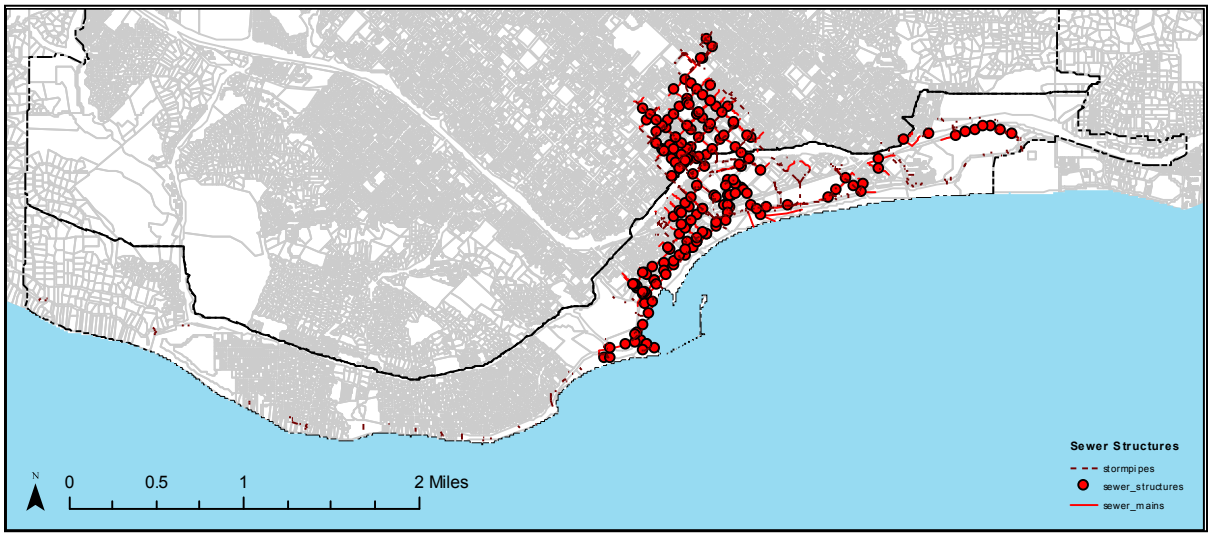

Figure D.1: Sewer structures within inundation and storm surge hazard zones.

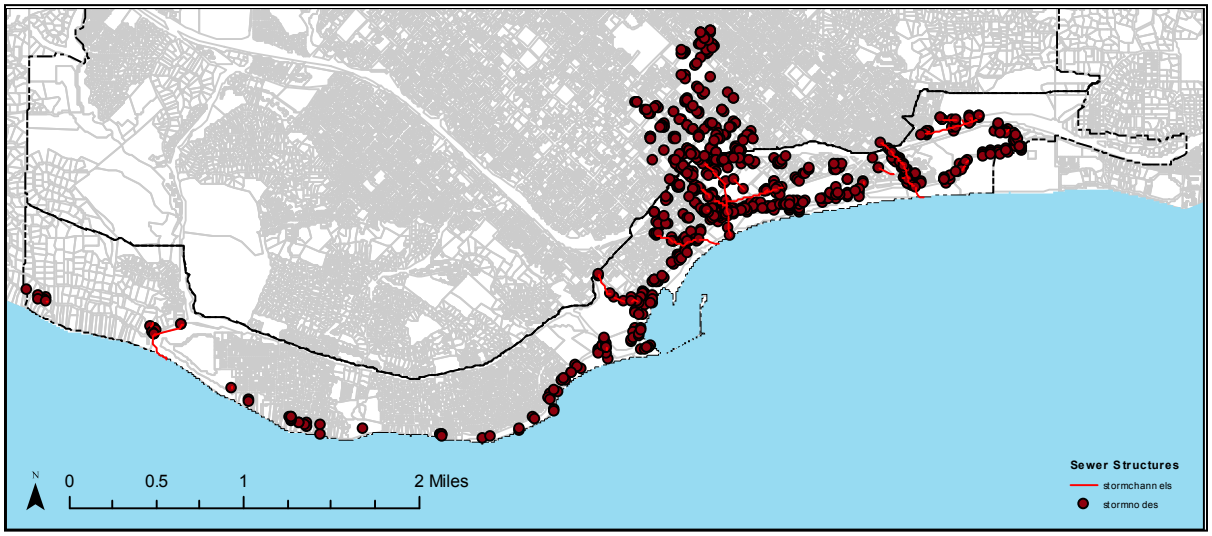

Figure D.2: Storm drains exposed within inundation and storm surge hazard zones.

Table D.9: Length of sewer mains exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Sewers mains exposed to inundation (ft)	Sewer mains exposed to 100-year storm (mi)
0.05	Low	2030	44	6.02
0.13	Low	2050	50	6.68
0.15	Medium	2030	49	6.87
0.28	Medium	2050	58	8.13
0.3	High	2030	58	8.27
0.44	Low	2100	66	9.29
0.61	High	2050	73	10.71
0.93	Medium	2100	675	12.71
1.67	High	2100	25314	14.51

Table D.10: Length of sewer structures exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Number of sewers structures exposed to inundation	Number of sewer structures exposed to 100-year storm
0.05	Low	2030	0	97
0.13	Low	2050	0	106
0.15	Medium	2030	0	109
0.28	Medium	2050	0	136
0.3	High	2030	0	138
0.44	Low	2100	0	157
0.61	High	2050	0	182
0.93	Medium	2100	3	187
1.67	High	2100	80	192

Table D.11: Number of storm drain nodes exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Number of nodes exposed to inundation	Number of nodes exposed to 100-year storm
0.05	Low	2030	1	341
0.13	Low	2050	1	364
0.15	Medium	2030	1	372
0.28	Medium	2050	2	428
0.3	High	2030	2	432
0.44	Low	2100	2	467
0.61	High	2050	2	517
0.93	Medium	2100	40	590
1.67	High	2100	290	738

Table D.12: Length of storm drain pipes exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Length of storm drain pipes exposed to inundation (ft)	Length of storm drain pipes exposed to 100-year storm (mi)
0.05	Low	2030	9	5.39
0.13	Low	2050	14	5.84
0.15	Medium	2030	14	5.96
0.28	Medium	2050	17	6.94
0.3	High	2030	17	7.03
0.44	Low	2100	22	7.79
0.61	High	2050	23	8.76
0.93	Medium	2100	904	13.14
1.67	High	2100	23529	14.22

Table D.13: Length of storm drain channels exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Length of storm drain channels exposed to inundation (mi)	Length of storm drain channels exposed to 100-year storm (mi)
0.05	Low	2030	0.02	1.67
0.13	Low	2050	0.03	1.73
0.15	Medium	2030	0.03	1.75
0.28	Medium	2050	0.05	1.77
0.3	High	2030	0.05	1.77
0.44	Low	2100	0.06	1.89
0.61	High	2050	0.23	1.97
0.93	Medium	2100	0.94	2.61
1.67	High	2100	1.56	2.91

Table D.14: Length of water mains exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Length of water mains exposed to inundation (mi)	Length of water mains exposed to 100-year storm (mi)
0.05	Low	2030	0.01	11.95
0.13	Low	2050	0.02	13.78
0.15	Medium	2030	0.02	14.19
0.28	Medium	2050	0.02	17.19
0.3	High	2030	0.02	17.49
0.44	Low	2100	0.03	19.59
0.61	High	2050	0.04	22.21
0.93	Medium	2100	0.23	26.23
1.67	High	2100	9.66	29.43

Table D.15: Number of fire hydrants exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Number of fire hydrants exposed to inundation	Number of fire hydrants exposed to 100-year storm
0.05	Low	2030	0	71
0.13	Low	2050	0	78
0.15	Medium	2030	0	80
0.28	Medium	2050	0	91
0.3	High	2030	0	92
0.44	Low	2100	0	101
0.61	High	2050	0	112
0.93	Medium	2100	1	113
1.67	High	2100	61	114

D.1.3 Erosion Results

Table D.16: Critical infrastructure exposed to erosion hazard.

Erosion Rate	Roads (mi)	Bikepaths (mi)	Storm Drain Channel (ft)	Storm Drain Nodes (Number)	Storm Drain Pipe (mi)
6	0.29	0.19	2.56	11	0.18
12	0.46	0.48	2.56	22	0.37
24	1.06	0.86	21.97	47	1.38

D.2 Human Populations Block Group Analysis of 2010 Census Data

Our sensitivity results for human populations using Decennial Census 2010 data at the block-group level turned out to be quite similar to the results using American Community Survey Data. The Census and ACS data differed by four variables. The Census did not have information on number of vehicles, people with poor English, or households with incomes below the poverty level. The Census data did contain institutionalized populations, which ACS did not have information on.

Using the same quantiles method as done with the ACS data, the Census sensitivity results differed by three block groups: H, I, and Q. Block groups H and I were found to have low sensitivity using ACS data but became medium sensitivity when using Census data. Block group H received a score of 3 for households with one or more person under the age of 18 as well as scores of 2 for renter-occupied households and 1-person households. With the ACS data block group H had no demographic variables that received 3 points. Block group I received a score of 3 for renter-occupied households, households with one or more person under the age of 18, and 1-person households. With the ACS data block group I only received 3 points for renter-occupied households.

Block group Q was classified as medium sensitivity using ACS data but became high sensitivity

using Census data. This block group received 3 points for 5 variables: renter-occupied households, households with one or more person under the age of 18, 5 or more person households, 1-person households, single parents, and householders over the age of 65. Using ACS data, block group Q received 3 points for renter-occupied households, 1-person households, and householders over the age of 65.

D.3 Ecological Resources

Table D.17: Creeks and wetlands exposed to inundation and storm surge.

SLR (m)	Projection	Year	Habitat exposed to inundation
0.05	Low	2030	Arroyo Burro Creek
0.13	Low	2050	Arroyo Burro Creek
0.15	Medium	2030	Arroyo Burro Creek
0.28	Medium	2050	Arroyo Burro Creek
0.3	High	2030	Arroyo Burro Creek
0.44	Low	2100	Arroyo Burro Creek
0.61	High	2050	Arroyo Burro Creek
0.93	Medium	2100	Arroyo Burro Creek, Mission Creek, Laguna Creek
1.67	High	2100	Arroyo Burro Creek, Mission Creek, Laguna Creek, Sycamore Creek

Table D.18: Wildlife habitats exposed to inundation and storm surge projections.

SLR (m)	Projection	Year	Habitats exposed to inundation	Habitats exposed to 100-year storm
0.05	Low	2030	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches
0.13	Low	2050	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches
0.15	Medium	2030	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches
0.28	Medium	2050	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches, Andree Clark Bird Refuge
0.3	High	2030	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches, Andree Clark Bird Refuge
0.44	Low	2100	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches, Andree Clark Bird Refuge
0.61	High	2050	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches, Andree Clark Bird Refuge
0.93	Medium	2100	Harbor Sandspit, Beaches	Harbor Sandspit, Beaches, Andree Clark Bird Refuge
1.67	High	2100	Harbor Sandspit, Beaches, Andree Clark Bird Refuge	Harbor Sandspit, Beaches, Andree Clark Bird Refuge

D.4 Recreation and Public Access

Table D.19: Recreation and public access sensitivity results.

Recreation and Public Access Site	Score	Rank
East Beach	19	High
Arroyo Burro Beach County Park	18	High
Santa Barbara Harbor	17	High
Chase Palm Park	16	High
Leadbetter Beach	15	High
Shoreline Park (Santa Barbara)	15	High
Stearns Wharf	15	High
West Beach	14	High
Los Baños del Mar	12	Medium
Santa Barbara Zoo	10	Medium
Dwight Murphy Field	9	Medium
La Mesa Park	9	Medium
Mesa Lane Stairs	8	Medium
One Thousand Steps	8	Medium
Pershing Park	8	Medium
Andree Clark Bird Refuge	7	Low
Plaza del Mar	7	Low
Skater's Point	7	Low
Cabrillo Ball Field	6	Low
Ambassador Park	5	Low
Overlook (Oliver Rd.)	5	Low
Douglas Family Preserve	4	Low

E Map of Results by Component Areas

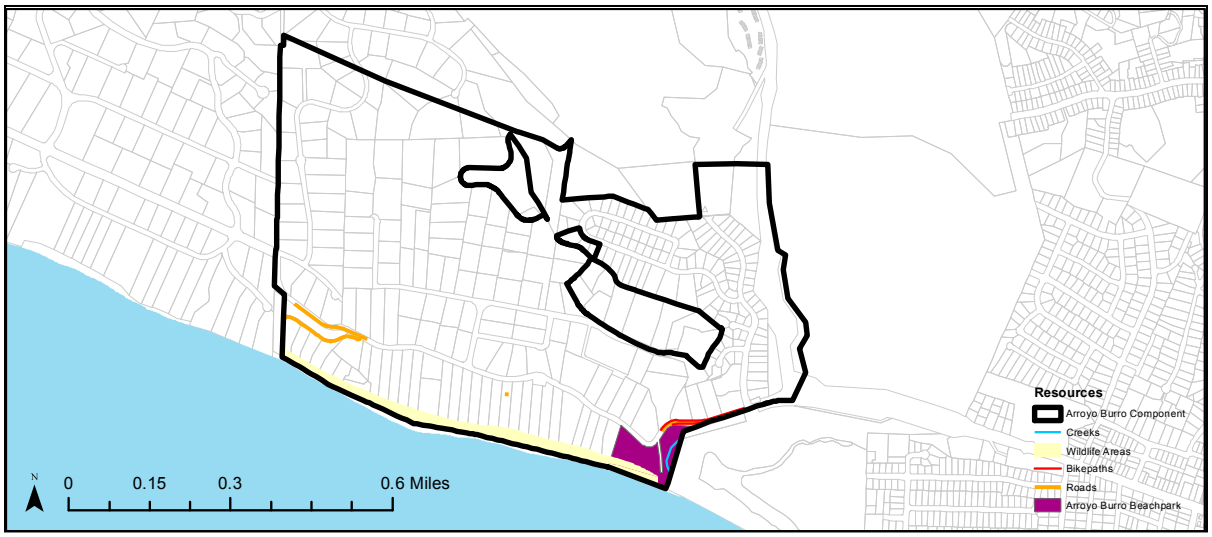

Figure E.3: Exposed resources within Arroyo Burro Component.

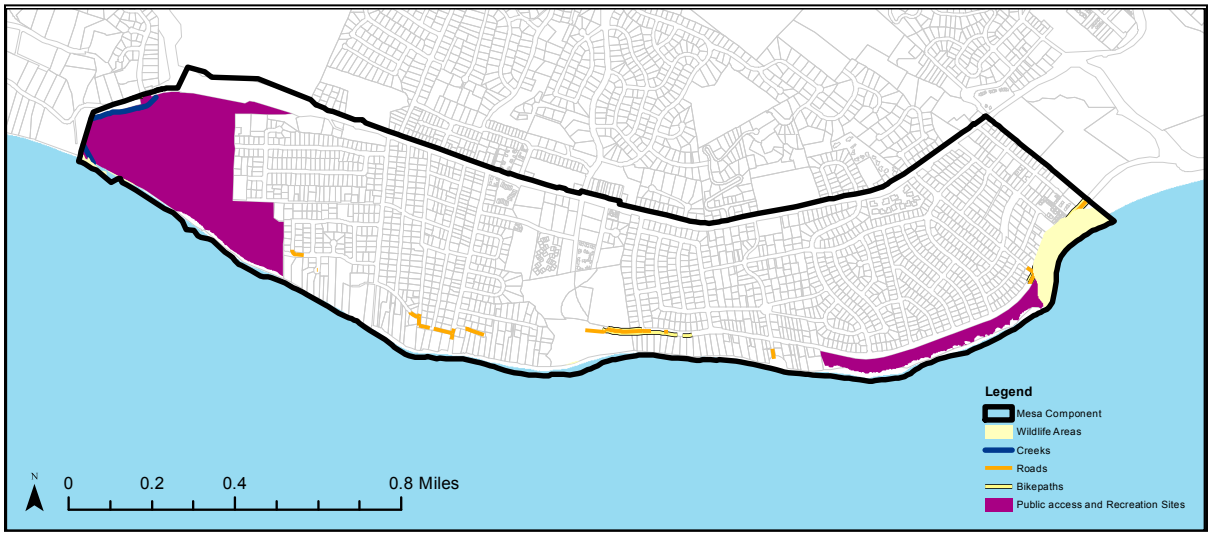

Figure E.4: Exposed resources within Mesa Component.

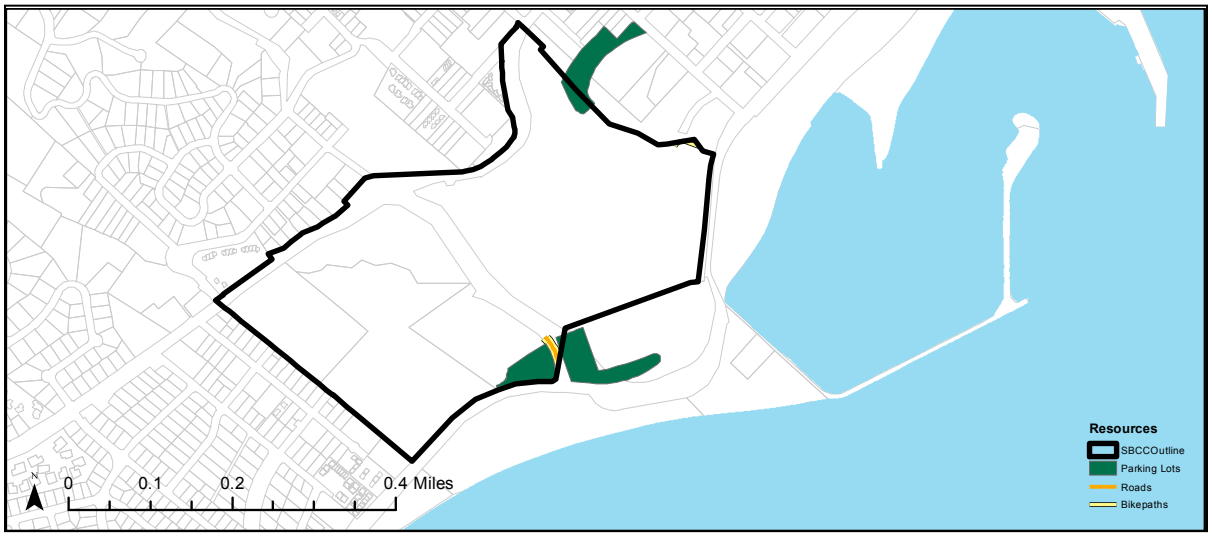

Figure E.5: Exposed resources within SBCC Component.

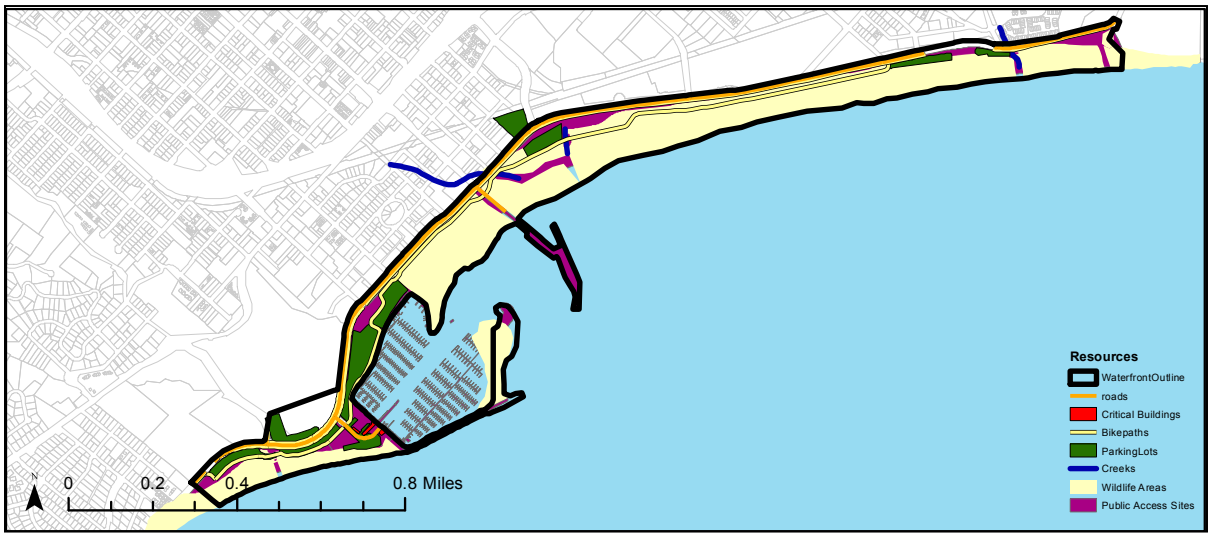

Figure E.6: Exposed resources within Waterfront Component.

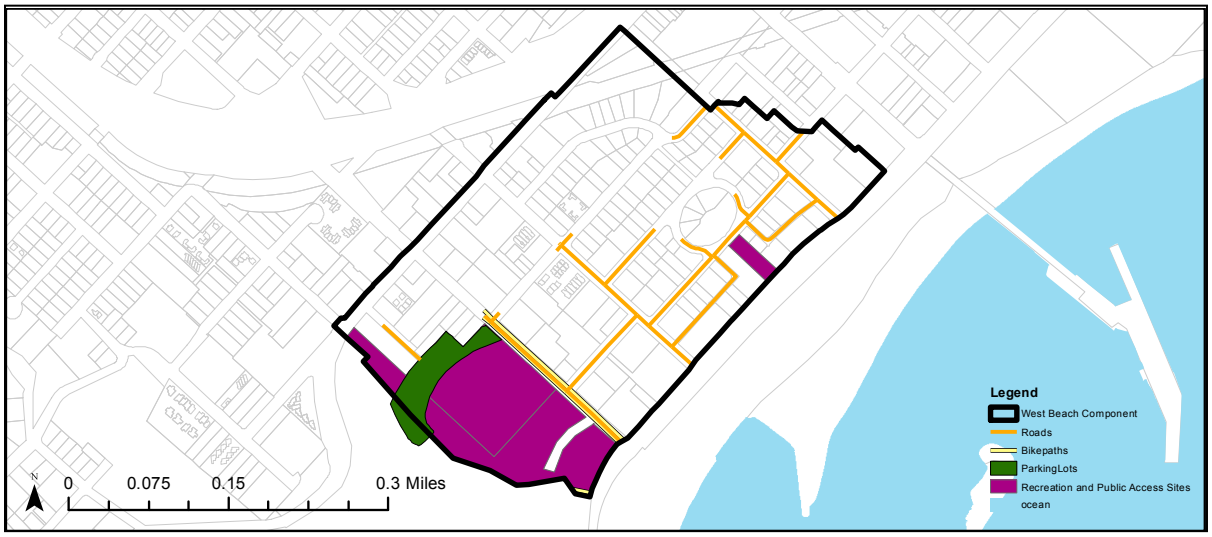

Figure E.7: Exposed resources within West Beach Component.

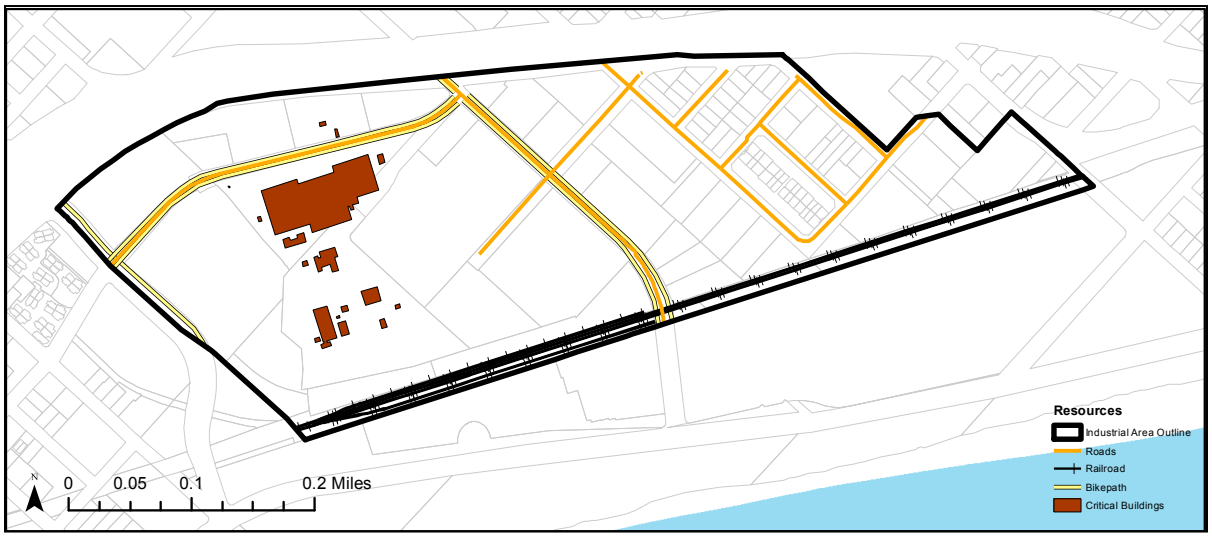

Figure E.8: Exposed resources within Industrial Area Component.

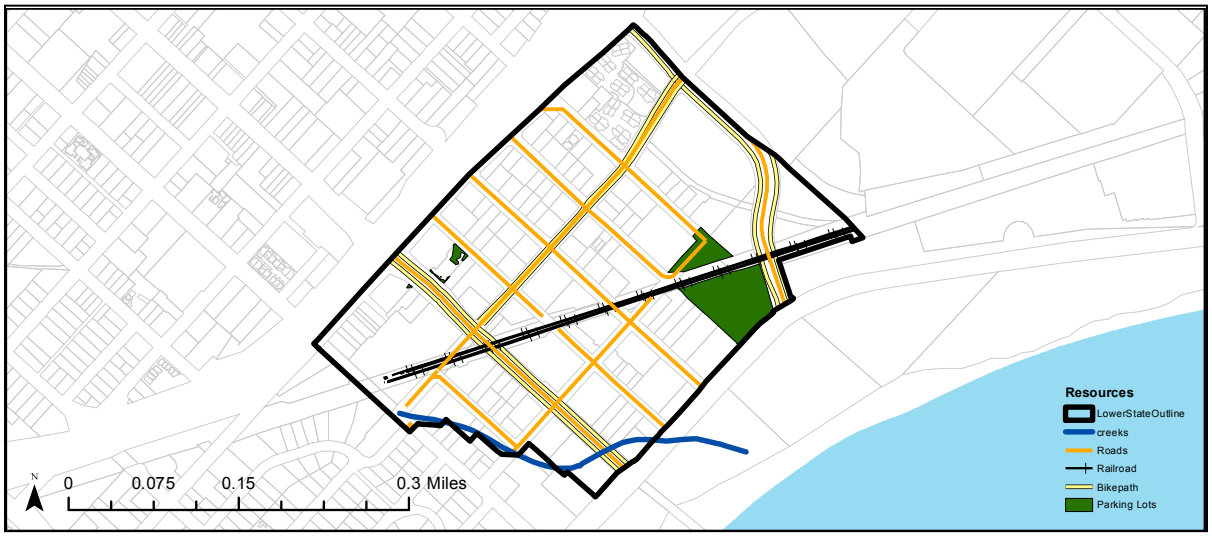

Figure E.9: Exposed resources within Lower State Component.

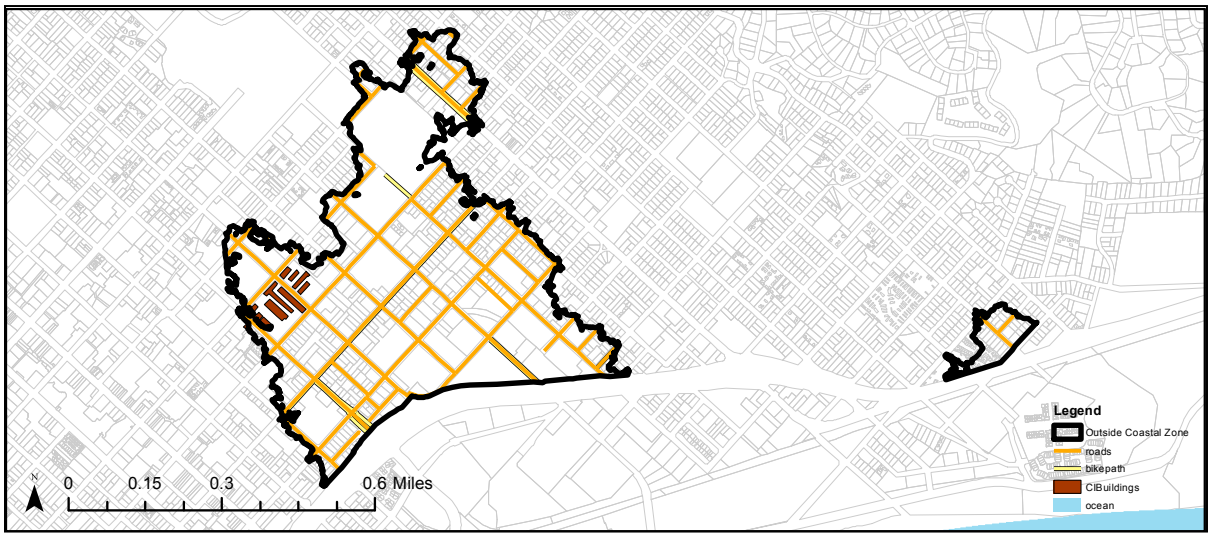

Figure E.10: Exposed resources outside of Component areas.

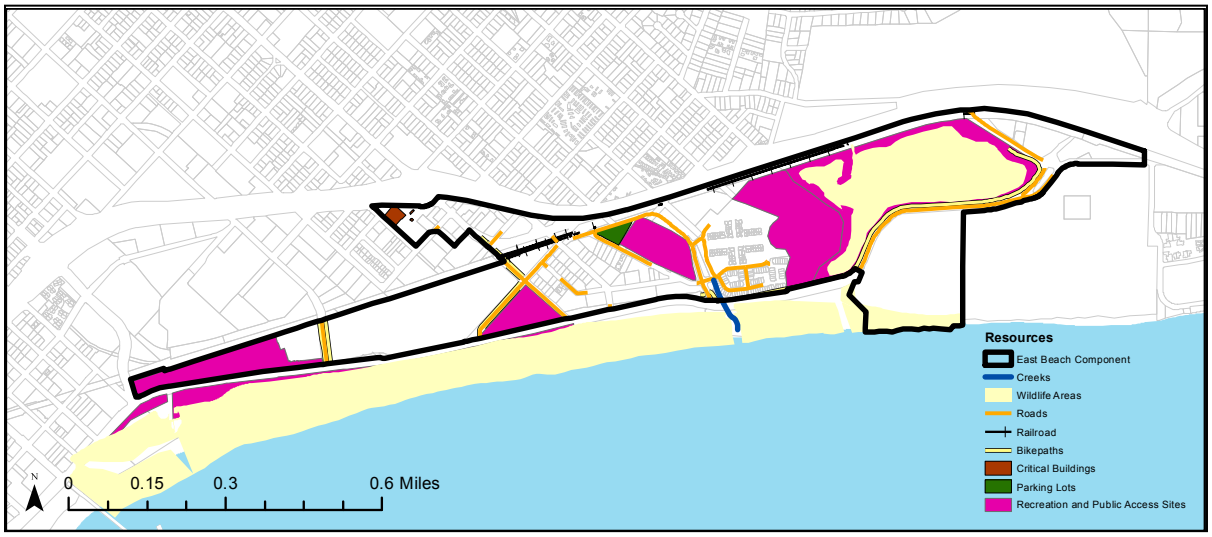

Figure E.11: Exposed resources within East Beach Component.

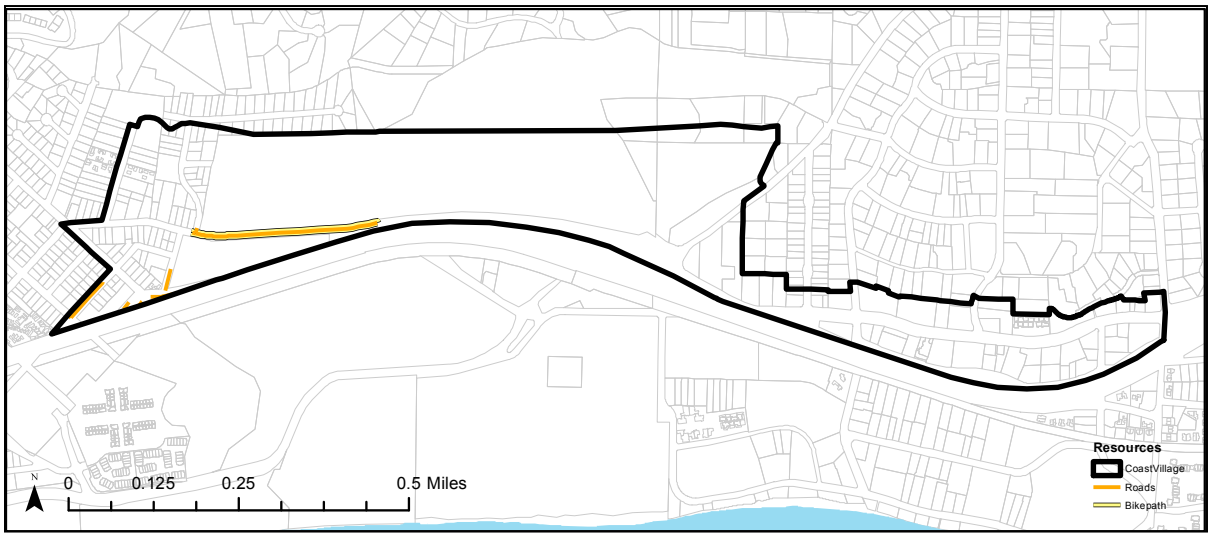

Figure E.12: Exposed resources within Coast Village Component.

F Hazard Zone Comparison with County's Modeling Project

The Santa Barbara County Coastal Resilience Project provided preliminary hazard zone layers describing wave runup, 100-year tides, back beach flooding, dune hazards, and cliff hazards. Each hazard contains projections for 2010, 2030, 2060, and 2100 and using the sea level rise projection of 1.03 m in 2100. This value comes from the NRC, 2012 projection of 0.93 m SLR in 2100 (the medium projection for 2100 in our analysis) but without the effects of subsidence to become 0.78 m SLR. Furthermore, the County study used the NRC medium projections +/- the standard deviation as their high/medium/low scenarios while our study used the full range of projections given in the NRC report for our high/medium/low scenarios.

The County hazard layers include much more comprehensive modeling than the hazard layers used in our report. For example, our hazard modeling does not include wave runup, dune migration, or fluvial flooding. However, our study does incorporate possible inundation hazards for everyday tidal conditions while these County hazard layers only portray the hazard effects that could be experienced during a major 100-year storm.

The comparable hazards between our study and the County are the layers describing cliff erosion, back beach flooding and 100-year tides (comparable to our storm surge layers). For cliff erosion, there are major differences between our layers and the layers modeled by the County (**Figure F1**). The main reason for this difference is the County cliff hazard zones represent erosion hazards during a major storm while our erosion zones represent non-storm conditions. Furthermore, the County incorporated large, historic cliff failures and local cliff geometry into the erosion rates for their cliff hazard zones. The erosion modeling used in our study is much more simplified approach using average historical erosion rates that may or may not describe past landslide events. Furthermore, due to uncertainty of the effects of sea level rise on erosion rates we included an arbitrarily doubled erosion rate (24 inches/year). Finally, for our study we only projected erosion hazards for a 75-year period (2090) while the County projected cliff hazards for 2010, 2030, 2060, and 2100. Overall, the erosion hazard zones used in our study could be a drastic underestimate of cliff hazards based on comparison with the County data.

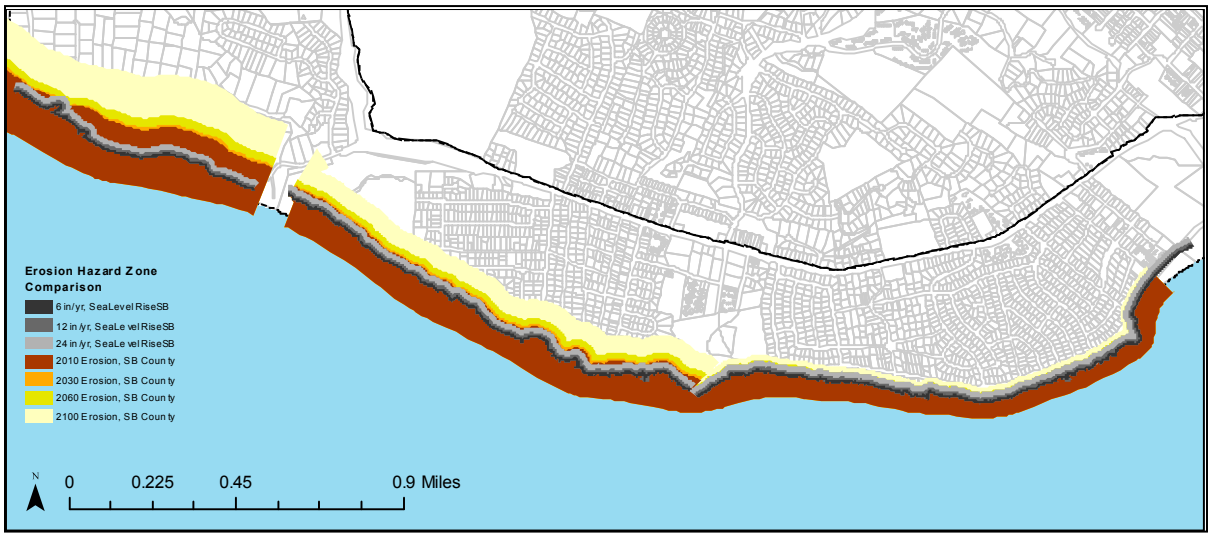

Figure F.13: Erosion hazard zone comparison with ESA PWA draft data.

Conversely, the back beach flooding layers combined with the 100-year tide zones provided by the County study are quite similar to our storm surge hazard zones for the 2030 (**Figure F2**) and 2100 high projections (**Figure F3**). The County's 2030 high back beach flooding zone combined with the 3.26 m 100-year tide zone includes approximately 40 acres more area than our 2030 high storm surge hazard zone (**Figure F4**). The largest area included in the County hazard zone but not in ours is located just west of El Estero Wastewater Treatment Plant. The County hazard zone also includes upstream areas of Mission and Arroyo Burro Creeks that were not included in our 2030 high storm surge hazard zone. This is most likely because our study did not take into account fluvial flooding.

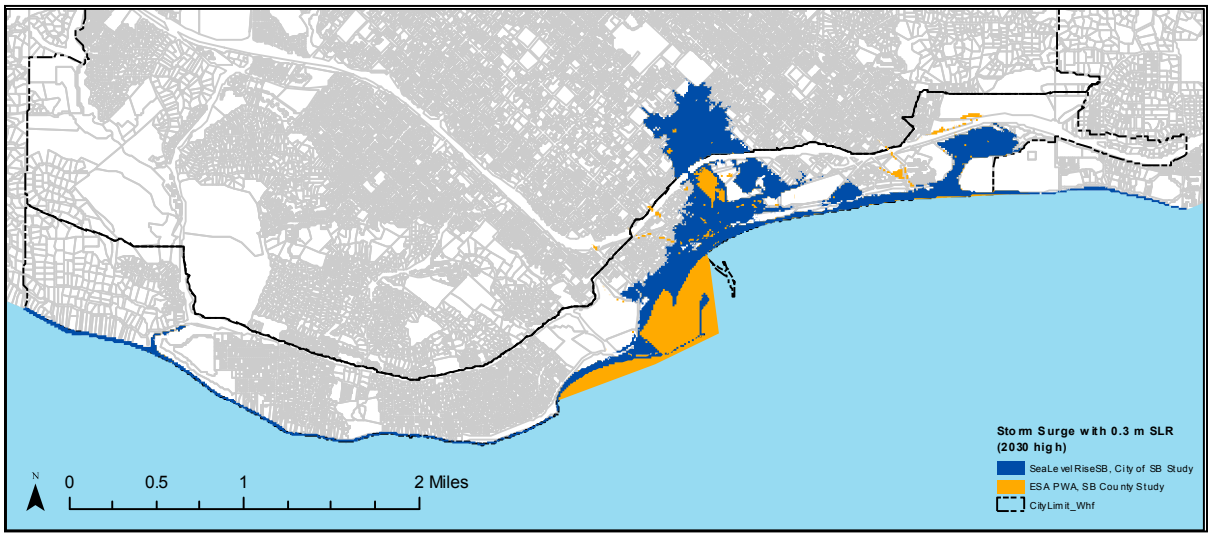

Figure F.14: Storm hazard zone comparison with ESA PWA draft data, 2030 High SLR.

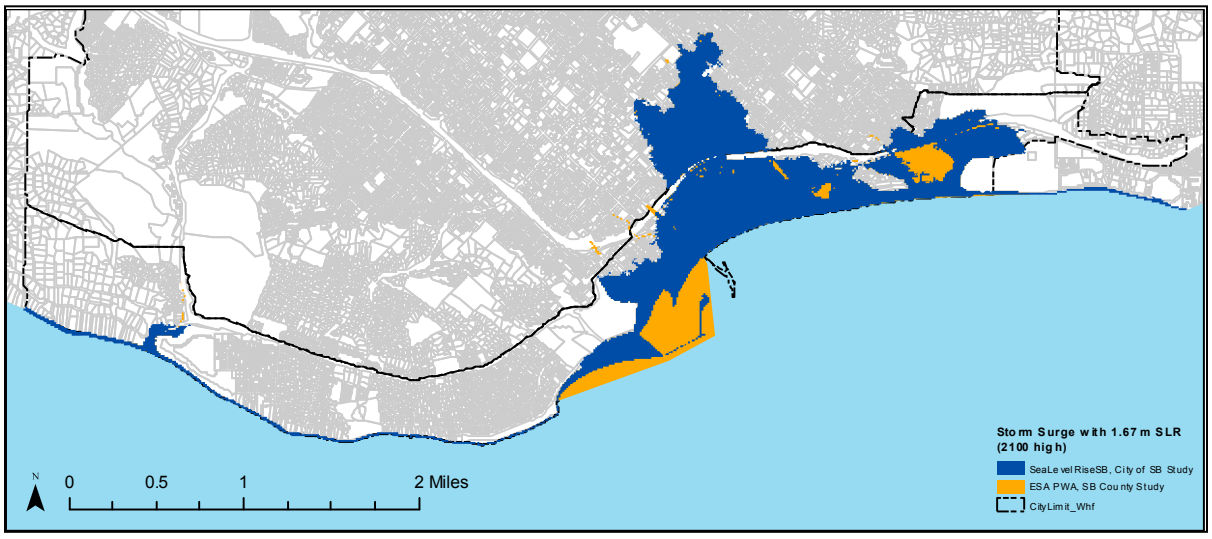

Figure F.15: Storm hazard zone comparison with ESA PWA draft data, 2100 High SLR.

Not including the 100-year tide zone covering the ocean, the County 2100 high back beach flood layer and 4.52 area 100-year tide layer combined describe a hazard zone approximately 80 acres larger than our 2100 high storm surge zone (**Figure F5**). The largest area that

is included in the County hazard zone but not in ours is located west of Andrée Clark Bird Refuge. Again, the County hazard zone also includes upstream creek areas that were not included in our 2100 high storm surge hazard zone.

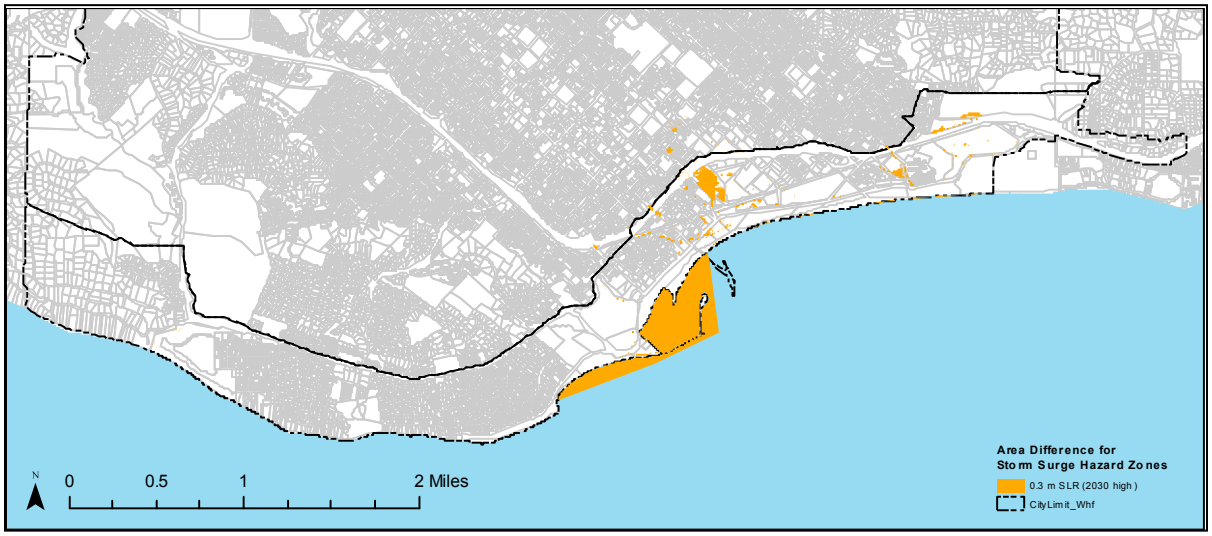

Figure F.16: Storm hazard zone area comparison with ESA PWA draft data, 2030 High SLR.

While there are many observable differences between the hazard zones modeled in our study and those modeled by the County, the storm surge hazard layers (referred to as back beach flooding and 100-year tides for the County) modeled in both studies are comparable. This similarity gives the storm surge hazard zones used in our study some credibility even though they are much more simplified. One beneficial use of comparing these or other modeled data layers is to overlap them to see what areas are always hazardous (**Figure F4** and **Figure F5**). Areas identified as hazard zones using multiple projections and/or datasets might be considered more likely to experience that hazard than areas that differ among studies.

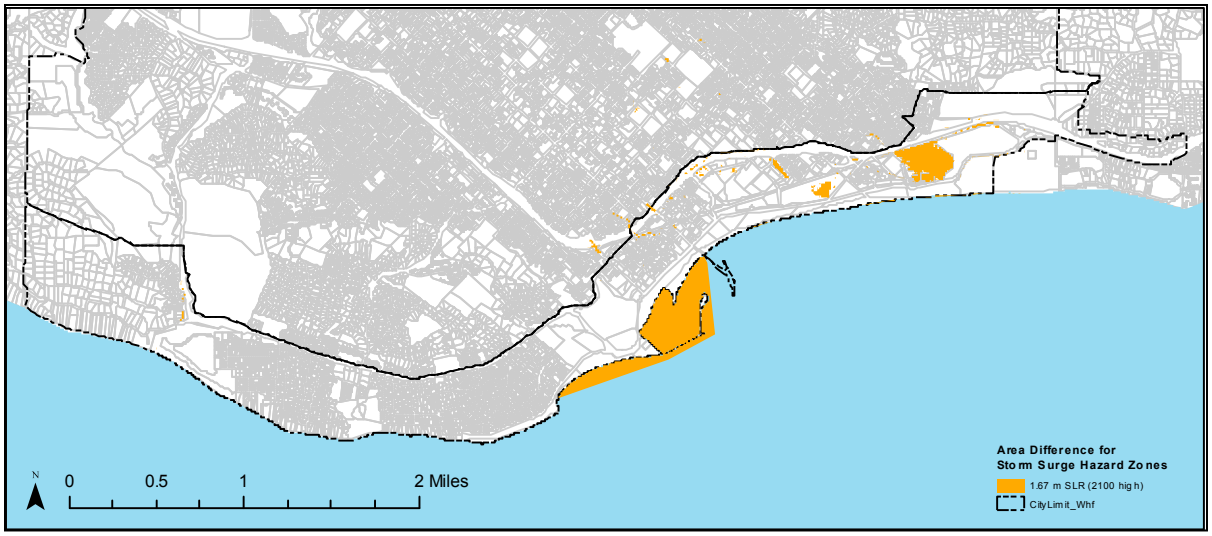

Figure F.17: Storm hazard zone area comparison with ESA PWA draft data, 2100 High SLR.

G City of Santa Barbara General Plan Policy Options and Discussion

Adaptation strategies can be divided into three major categories: to retreat, accommodate, or protect (IPCC, 2014, Chapter 17). A number of tools and frameworks exist to help a community decide how, where, and when to implement one of these adaptation strategies. With an overarching goal of sustainability, the City adopted an Adaptive Management Program (AMP) for the implementation of its General Plan (City of Santa Barbara, 2011, Introduction). Adaptive management sets up a method to track the progress of City goals, policies, and implementation measures and gives the City the ability to revise these measures where they are either ineffective or have adverse or unintended consequences.

Additionally, adapting to climate change risks is overall most successful when policies address wider social and economic concerns like disaster protection and preparedness. The City cares deeply about protecting the health and safety of its citizens, and has numerous goals, policies, and implementation measures in place to protect its citizens from many current and potential hazards. The following section discusses current goals and policies within the City of Santa Barbara and potential ways in which these goals may be enhanced to further incorporate sea level rise vulnerability. Planning documents discussed in this section include the recently updated Santa Barbara General Plan (2011)–especially the Safety Element, the City's award-winning Climate Action Plan, and the 2011 Santa Barbara County Multi-Jurisdictional Hazard Mitigation Plan.

General Plan

The General Plan for the City of Santa Barbara is created to protect the health, safety, and welfare of its citizens with a central mission statement of "Living Within Our Resources" (City of Santa Barbara, 2011, p. 1). The General Plan is the central guiding document for development within the City, and its goals and policies are designed to help address the multitude of issues involved with urban development in such a beautiful and geologically dynamic city. Specifically, the updated General Plan focused on five key policy drivers: "Economic and Fiscal Health, Historic and Community Character, Growth Management, Public and Community Health, [and] Energy and Climate Change" (City of Santa Barbara, 2011, p. 2). Sea level rise has the potential to impact all of these key issues.

Economic and Fiscal Health

This issue revolves around economic fluctuations, affordable housing, and "worker recruitment and retention (City of Santa Barbara, 2011, Introduction, p. 3). Financial concerns for the City revolve around maintaining and upgrading public services and facilities in the face of long-term increasing costs. Sea level rise response will increase City expenditures, whether by post-disaster response or pre-disaster planning and adaptation. Major questions for the City will continue to revolve around where and when to take action. Risk management involved the balancing of providing for current needs while protecting citizens from future hazards.

Historic and Community Character

The impact of sea level rise on the historic and community character of the city are twofold: first,

permanent inundation may eventually threaten historic open spaces along Santa Barbara's waterfront. Protecting or abandoning these sites will change the visual aesthetics of the town, ultimately decreasing overall open space within the city without clear visions to protect overall open space. Second, development projects within Santa Barbara are primarily redevelopment or "in-fill" projects. Increasing flood protection measures may result in changes to the aesthetics of Santa Barbara's building stock, and could result in the need for increased building height allowances.

Growth Management

Sea level rise policy has the potential to be at odds with other climate change and sustainable development policies that aim to maintain and increase the affordability of housing stock with high density incentives. Addressing sea level rise in this context will mean ensuring that the City's encouragement of high density housing (by means of incentives and programs) be focused in lower risk locations where possible and/or to protect structures to minimize risks to health and safety. Any development limits placed on any portion of the City may increase housing costs and decrease the availability of affordable housing, especially as coastal housing stock ages and homeowners and developers face increasingly strict limits on developments or expensive retrofits. Strategies of relocation or retreat also face challenges within this policy driver: if the City needs to relocate housing or infrastructure in addition to accommodating more housing for an increased future population, where can all of these structures go? If the City continues to promote infill for cost-based and environmental reasons, opportunities for relocation of properties may decline. A question for the City: what is the optimal point between population growth and sea level rise where the City will have the greatest opportunities for infill or other relocation strategies at the lowest costs?

Public Health

Safe biking and walking routes and recreational open spaces promote public health. Continuing to provide these services with increases in sea level are important. Sea level rise has the potential to affect public health by increasing the City's exposure to storms and eventually decreasing open space as open areas become inundated. Storms have the potential to cause physical damage to people and infrastructure as well as psychological damages in the case of large, disaster-type situations. The potential that climate change may increase the frequencies of storms or storm wave height could translate into even higher risks to recreational facilities (e.g. damaging the multi-modal beachway along East Beach) and critical infrastructure (e.g. Wastewater Treatment processing).

Energy and Climate Change

The City's main focus in addressing energy and climate change revolves around transportation for its fuel demand and its contribution to climate change. The main interaction between sea level rise and more general climate change concerns relates to the allocation of economic resources for planning purposes. However, decreasing the community's reliance on single occupancy vehicles may affect the population's sensitivity to disasters: road congestion for evacuation or emergency response purposes would decrease, but an individual's ability to evacuate or actively reach emergency services would also decrease. A secondary issue is one of the environmental costs of rebuilding, raising, or relocating a structure. In addition to noise, pollution, and traffic congestion concerns, construction work additionally will add to the

greenhouse gas emissions for the City as a whole. These emissions could pose problems with meeting the City's greenhouse gas emissions targets. While the increased emissions for Santa Barbara itself will have a small impact worldwide, sea level rise adaptation practices worldwide may have significant effects on global atmospheric greenhouse gases.

Goals and Policies within the General Plan Related to Our Project

Goal: Fostering Public Participation. The City provides a public participation process that is inclusive, responsive, and balanced with regard to the broad needs of the community. (City of Santa Barbara, 2011, p. 12)

Public involvement will be critical for prioritizing adaptation strategies to sea level rise because some policies will be in conflict with other goals such as affordable housing (IPCC, 2014, Chapter 5, p. 394). Policy PP1 states that "Members of the public shall have access to the necessary information and understanding of procedures to participate in decisions that affect them" (City of Santa Barbara, 2011, p.12). This Sea Level Rise Vulnerability Assessment and especially the forthcoming Communications Strategy for Public Awareness and Involvement are designed to inform both City staff and the public about specific vulnerabilities and hazards to sea level rise within Santa Barbara in addition to help guide policy visioning.

Relevant Land Use Element Policies

LG4. Principles for Development: Focus Growth. Encourage workforce and affordable housing within a quarter mile of frequent transit service and commercial services through smaller units and increased density, transit resources, parking demand standards, targeted infrastructure improvements, and increased public areas and open space. (City of Santa Barbara, 2011, Land Use Element, p.49)

Specifically addressing particularly hazardous locations for high density might include setbacks from creeks beyond standard policies or increased building standards within hazard zones. Locating highest density housing within the most hazardous areas has the potential to exacerbate storm and flooding hazards to human health, especially if roads become inaccessible and emergency service vehicles are unable to respond to a particular location.

LG5. Community Benefit Housing. While acknowledging the need to balance the provision of affordable housing with market-rate housing, new residential development in multi-family and commercial zones, including mixed-use projects, should include affordable housing and open space benefits. (City of Santa Barbara, 2011, Land Use Element, p.50)

This policy calls for open space benefits with a possible implementation action including open space dedication or in-lieu fees for future parks. In lieu fees have the potential to fund restoration and soft armoring strategies to decrease vulnerability to waves and flooding or to purchase additional park area, especially if dredging efforts are insufficient to keep the wide, sandy waterfront beaches.

LG6. Location of Residential Growth. Encourage new residential units in multi-family and commercial areas of the City with the highest densities to be located in the Downtown, La Cumbre Plaza/Five Points area and along Milpas Street. (City of Santa Barbara, 2011, Land Use Element, p.50)

Consider an implementation action similar to LG6.5 (limiting growth in high fire areas) that limits new residential development in the floodplain. Transferring development rights or incentivizing limiting growth would be options to implement. Where high density and floodplain area overlap, special considerations should be taken. Consider disincentivizing growth with a setback-like policy that limits the density of growth within a buffer of a river or the coast. For example, a lower-density zone could be established within 100 feet of rivers or 200 feet of the low-lying coast where densities within the buffer are slightly less than currently designated zones. While 200 feet is relatively arbitrary, consider increasing the coastal buffer zone relative to a stream to account for wave runup hazards.

LG15. Sustainable Neighborhood Planning. Neighborhoods shall be encouraged to preserve and enhance the sense of place, provide opportunities for healthy living and accessibility, while reducing the community's carbon footprint. (City of Santa Barbara, 2011, Land Use Element, p.56)

This policy is not directly applicable to SLR, but has the opportunity to be used in conjunction with disaster-planning and community building, which will increase overall resilience of the City, especially LG15.1 possible implementation action of Sustainable Neighborhood Plans. Consider ensuring that housing opportunities for the homeless, disabled, and low-income citizens are not located in the same location or all within similar hazard zones (e.g. flooding, fire, earthquake).

R1. Regional Planning. Work cooperatively with the County and other local jurisdictions through the SB375 process to better coordinate land use and transportation planning, including the provision of affordable housing. (City of Santa Barbara, 2011, Land Use Element, p.57)

This regional governance policy includes one area to include evacuation and disaster long-range planning for transportation. It may also make altering high density zones more difficult.

Relevant Housing Element Policies

H6. Housing Opportunities for Seniors. Seek to ensure the availability of a range of housing opportunities with an emphasis on extremely, very low, low and moderate income seniors. (City of Santa Barbara, 2011, Housing Element, p.95)

H7. Housing Opportunities for Disabled. Seek to ensure the availability of a range of housing opportunities for the extremely low, very low, low and moderate income disabled populations. (City of Santa Barbara, 2011, Housing Element, p.96)

Consider implementing actions to encourage senior and disabled housing in low-risk areas. Lower risk areas within the low-lying waterfront area are within the City's Local Coastal Program West Beach component. Coast Village and East Beach components are relatively low risk to coastal hazards, but may not have great opportunities for development and may be subject to greater fluvial flooding risks. Consider encouraging housing with close proximity roads with higher accessibility to emergency services, especially during storm conditions.

H20. Property Improvements. The City shall encourage residential property owners to improve the conditions of their property(ies) to a level that exceeds the minimum standards

of the California Building Code and the Uniform Housing Code. (City of Santa Barbara, 2011, Housing Element, p.96)

Possible implementation actions focus around enforcement. Consider fees for substandard buildings that fund housing improvements, including increasing a building's resilience to flooding.

Relevant Open Space Element Policies

Goal: Open Space Opportunities. Protect and enhance the City's livability, accessibility and character, and the community's health, through the generous provision of a variety of accessible public open space opportunities. (City of Santa Barbara, 2011, Open Space Element, p. 3)

OP1. Variety and Abundance. Provide ample open space through a variety of types, including nature reserves, parks, beaches, sports fields, trails, urban walkways, plazas, paseos, pocket parks, play areas, gardens, and view points, consistent with standards established for this city. (City of Santa Barbara, 2011, Open Space Element, p. 3)

A possible implementation action mentioned includes an open space to resident ration (per 1000 residents); losing beach area could increase needs for other open space even with a stable population.

OP2. Open Space, Park, Recreation and Trails Acquisition and Maintenance Funding. The City shall develop a variety of ways and options to support acquisition and maintenance of public open space, and new development and re-development shall contribute commensurate with the incremental need generated. Access and connectivity between open spaces shall be considered in future acquisition and maintenance funding. (City of Santa Barbara, 2011, Open Space Element, p. 4)

Continue this program. Consider documenting changes to open space areas, especially if/when sea level rise begins encroaching on some open space areas. For many of the sea level rise hazards, setting up a system of measurement and data sharing will increase knowledge regarding current conditions and will increase the reliability of future model to project changes to various systems within Santa Barbara.

Relevant Economy and Fiscal Health Element Policies

EF24. Coordinate with UCSB. Develop closer ties with UCSB, recognizing its role as a major source of stimulus for growth on the South Coast and as an employment base and source of start-up businesses. (City of Santa Barbara, 2011, Economy and Fiscal Health Element, p. 5)

Data sharing and continuing collaborative research projects may help continue to strengthen this bond. For example, the City could work with Bren School professor Gary Libecap to have his Cost-Benefit Analysis course focus on a City concern to conduct a Cost-Benefit Analysis together as a class for their final report. This could cover any number of topics, and would not necessarily revolve around sea level rise.

EF26. Development Impact Fees. To the extend applicable, in order for the community to function more sustainably, new commercial and market-rate residential development and

redevelopment shall either avoid impacts on community services and facilities, or contribute financially to the City or other community organizations to mitigate such impacts and costs of providing increased services and facilities. (City of Santa Barbara, 2011, Economy and Fiscal Health Element, p. 5)

Consider applying funds for development impact fees towards disaster planning and response, and a "rainy day fund" to reduce reliance on federal support after a disaster.

EF28. Financing Capital Improvements. The City shall pursue a variety of financing sources for the maintenance and enhancement of capital improvement projects. (City of Santa Barbara, 2011, Economy and Fiscal Health Element, p. 6)

This policy should be continued. Consider paying close attention to any disaster mitigation grants available at the regional, state, and federal level.

Historic Resources Element Policies

HR1. Protect Historic and Archaeological Resources. The City shall pursue a variety of financing sources for the maintenance and enhancement of capital improvement projects. (City of Santa Barbara, 2011, Historic Resources Element, p. 9)

HR6. Protect Traditional Public Resources and Streetscapes. Identify and preserve significant public resources and streetscapes and ensure a public review process in order to protect their historical features and attributes. (City of Santa Barbara, 2011, Historic Resources Element, p. 13)

HR7. Protect Cultural Landscapes. Identify and preserve historic landscapes. (City of Santa Barbara, 2011, Historic Resources Element, p. 3)

Creating a priority list of important structures will help rank facilities to see which, if any, structures should be protected at all costs. Certain historic structures may lose their character through waterproofing standards at which point a seawall or flooding wall may seem like an attractive alternative. If a seawall is to be considered for any facility, it should be identified early in order to give the City time to construct a very compelling design and case to the Coastal Commission. The political climate of the Coastal Commission will determine ultimately if such a structure would be permitted; current guidance documents stress this type of solution as a last resort and as one that is not likely to be implemented. Conducting an extensive City-wide sea level rise and fluvial hazards modeling assessment that takes into consideration hydraulic processes and connectivity through engineered structures such as storm drains will help in the maintenance and enhancement of various capital improvement projects. First, the threshold elevations at which various infrastructures will be subject to failure can be determined. It may be a gradual process, for instance for the backing up of storm drains, but there may be a threshold range at which flooding impacts may reach another stage of emergency.

HR2. Protect Ensure respectful and compatible development. Seek to ensure that all development within the neighborhood and the overall historical character of the city. Assure compatibility of development, respect for the historical context of historical resources, and consideration of sustainable design alternatives where compatible. (City of Santa Barbara, 2011, Historic Resources Element, p. 10)

HR2.4 offers the implementation option to assess potential long-term damage to a structure. Consider including explicitly that increasing its exposure to hazards such as sea level rise-related ones. This could require a more detailed analysis for projects that could potentially exacerbates. A clear example of a project that might do that would be a neighboring protective structure that might increase erosion of the beach or cliff nearby. Practically, the structures at risk here would be off of streams, so this would not necessarily be for only direct coastal impacts such as wave runup. To some extent, this protection is offered through building standards that limit significantly increasing the flooding potential of neighboring locations.

HR8. Survey and Document All Historic Resources. Continue to identify, document, and designate individual historic resources, as well as historic areas. (City of Santa Barbara, 2011, Historic Resources Element, p. 13)

Consider adding to a dataset with documented historic resources whether or not the resource is within any hazard zones identified by the City of Santa Barbara. Consider sea level rise when assessing the safety of historic buildings and continue to identify measures to decrease hazard risks to these facilities while maintaining their historic character.

HR10. Assure Governmental Effectiveness. Provide adequate resources to enable implementation of the goals and policies within this Element. Ensure coordination between agencies and review bodies at all levels of government by every means, including provision of easy access to all relevant information and materials. (City of Santa Barbara, 2011, Historic Resources Element, p. 15)

Consider establishing a committee of relevant stakeholders from various City departments to develop a list of resources of high priority in addition to a method for establishing prioritization. Tasks of this group could include devising an extensive list of concerns relating to sea level rise, collecting and/or aggregating on-the-ground data for existing structures into data that is useful for analysis, researching and applying for sea level rise-related grants, and developing projects for consideration within the six-year capital improvements project plan and the yearly capital budget. Consider establishing a GIS database for assets, projections, and concerns related to sea level rise planning. It may be prudent to widen the scope of the committee/database to include planning for all natural disasters hazards.

Environmental Resources Element Policies

ER1. Climate Change. As applicable, private development and public facilities and services may be required to incorporate measures to minimize contributions to climate change and to adapt to climate changes anticipated. (City of Santa Barbara, 2011, Environmental Resources Element, p. 4)

To a large degree, this policy has been implemented through the City's Climate Change Action Plan. More detailed policies can be found within the Safety Element. However, it should be noted that efforts to adapt to sea level rise may be at odds with other policies to reduce greenhouse gas emissions. A carbon market at the local or regional level could alleviate concerns for increased emissions due to building protection or relocation in a cost-effective way.

ER2. Emergency Response Strategies and Climate Change. The City shall incorporate

into its response strategies for emergency preparations, the potential effects of climate change, including from extreme weather, sea level rise, or epidemics, on humans and the built natural environment. (City of Santa Barbara, 2011, Environmental Resources Element, p. 4)

This is a very important strategy that can address hazard preparedness in a comprehensive way. Further opportunities exist for coordination with the Office of Emergency Services to incorporate sea level rise, especially increased flooding, into disaster response planning efforts. Integrating sea level rise in the next update of the County's Multi-Jurisdictional Hazard Mitigation Plan will aid this effort.

ER4. Incorporation of Adaptation in Development. New public and private development or substantial redevelopment or reuse projects shall estimate the useful life of proposed structures, and, in conjunction with available information about established hazard potential attributable to climate change, incorporate adaptation measures in the design, siting and location of structures. (City of Santa Barbara, 2011, Environmental Resources Element, p. 4)

This is a good policy. Effective implementation requires careful strategies that address the risks of climate hazards such as sea level rise. Possible Implementation Action (ER4.2) explicitly offers recommendations for ways to "identify policy options, costs, and consequences for addressing sea level rise" (City of Santa Barbara, 2011, Environmental Resources Element, p. 4). Previously mentioned collaboration with UCSB is one strategy to address potential techniques to implement the strategy. Working with professors in various departments (e.g. Environmental Science, Bren School of Environmental Science, and Engineering) to assign class papers focused on the City or region of Santa Barbara may be a good strategy for creative idea generation, critical for climate change responses with two additional benefits: increasing collaboration with UCSB and helping develop a sense of community for students who rotate through Santa Barbara in addition to those who stay.

ER12. Wildlife, Coastal, and Native Plant Habitat Protection and Enhancement. Protect, maintain, and to the extent reasonably possible, expand the City's remaining diverse native plant and wildlife habitats, including ocean, wetland, coastal, creek, foothill, and urban-adapted habitats. (City of Santa Barbara, 2011, Environmental Resources Element, p. 8)

Possible Implementation Actions ER12.2 (Multi-Use Plan for Coasts and Native Habitat Restoration) and ER12.3 (Coastal Bluff Habitat Restoration Program and Protection) have the potential to decrease the City's vulnerability to sea level rise related hazards. These policies may be emphasized for their dual purpose. Developing priorities for these habitats that serve dual purposes may help make it easier in the future if the City must decide between protecting one particular habitat over another. Coastal bluff restoration will also decrease erosion hazards overall, regardless of sea level rise.

ER20. Storm Water Management Policies. The City's Storm Water Management Program's policies, standards and other requirements for low impact development to reduce storm water run-off volumes, rates, and water pollutants are hereby incorporated into the General Plan Environmental Resources Element. (City of Santa Barbara, 2011, Environmental Resources Element, p. 13)

Consider updating guidelines under this policy to include either an increased hazard zone to

focus stormwater efforts. Consider updating floodplain maps to include various levels of sea level rise.

ER21. Creek Setbacks, Protection, and Restoration. Protection and restoration of creeks and their riparian corridors is a priority for improving biological values, water quality, open space, and flood control in conjunction with adaptation planning for climate change. (City of Santa Barbara, 2011, Environmental Resources Element, p. 13)

Consider incorporating a policy similar to this that deals with sea level rise and coastal flooding, or expanding the scope of this policy to include coastal flooding. Coastal flooding may be directly from the ocean or by exacerbating fluvial flooding by decreasing output opportunities.

ER29. Visual Resources Protection. New development or redevelopment shall preserve or enhance important public views and viewpoints for public enjoyments, where such protection would not preclude reasonable development of a property. (City of Santa Barbara, 2011, Environmental Resources Element, p. 14)

Consider creative solutions to incorporate increased flood protection with this policy that also protects visual resources.

Circulation Element Policies

C8. Emergency Routes. It shall be a high priority to keep all emergency evacuation, response and truck routes free of physical restrictions that may reduce evacuation/response times. (City of Santa Barbara, 2011, Circulation Element, p. 7)

Consider adding policies to increase the identification of emergency routes and public education regarding emergency coordination in the event of larger disasters.

General Plan Safety Element Policies

The General Plan Safety Element is the most relevant source for policies that address natural hazards within Santa Barbara. A list of the most relevant policies is listed in **??**.

Regarding Relevant Policies Within the Safety Element

For policy S46, consider expanding the redevelopment requirements to include a wider floodplain to incorporate sea level rise increasing the flooding areas. Additionally, current regulations require building to a designated Base Flood Elevation. Consider including policies to add a higher buffer for floodproofing requirements or raising habitable floor elevation. The two ideas here are increase the resilience of a structure that is already within a 100-year flood zone, and to expand the area where buildings are protected. Consider an "intermediate" zone that is projected to become a future flood zone but outside of FEMA-designated zones for transitional policies that add to a structure's resilience. This could be in the form of an incentive, a loose version of the requirements within S46, or full protection.

Foreseeable problems in increasing the flood zone map area include whether or not to incorporate a changing flood zone (akin to a 75-year cliff erosion line) to account for rising risks and which value (or values) of sea level rise to use for this evaluation. A moving target would be more difficult to continually update, but easier to manage adaptively with "best available science." Creating a committee to establish specific regulatory standards to make some of these decisions as mentioned in relation to policy HR10 is one means by which to do this.

S50. Consider making this policy more specific to provide a vision or direction for assessment reports, including time components of concern. It says to adapt to changes that may occur. Without adaptation efforts (including the continued maintenance of flood protection devices, hazards will occur, even if not exactly as projected. While it is highly unlikely that downtown Santa Barbara will be part of the ocean tides with 1.7 meters of sea level rise, without adaptation it will happen at some distant future time because we are committed to sea level rise for at least a few hundred years, if not longer. Some adaptation measures include existing structures like the Laguna tide gate?maintaining or improving this facility will be an important coastal flood protection measure. For all coastal assets it is a matter of what to maintain, what to improve, and what to restore (retreat or more simple restoration operations such as those included in current infrastructure projects like the Cabrillo Bridge renovation). Even more than that, however, is the question of timing and thresholds.

Policy S50 is more like a heading for policies S51 through S55 (but especially S51, S52, and S53)?monitor how and when, assess how and how often, and adapt how and when.

Consider establishing threshold sea level rise values that trigger certain adaptation strategies. This will include needing someone to establish when that threshold has been triggered because sea levels vary significantly year-to-year. One potential option would be to compare maximum observed values of water heights in the present and past. While this would not give an exact "sea level rise" amount, something like this would help people realize that water levels were higher. Again, this could be established by a committee or discussions with scientists. Problems with this approach include the fact that there are a very limited quantity of data for Santa Barbara's tide gauge, and 17 years of data may or may not capture some of the extreme water levels.

S51(a). Good. Consider establishing a plan for maintenance, replacement, or redundancy within this tide gauge. It will be vitally important for determining amounts and rates of SLR with another 10-20 years of data. Communicate and coordinate with NOAA to determine any additional protection measures that the City could put in place or do to increase protection.

Table G.20: Safety element policies relevant to sea level rise.

Policy Number	Category	Basic Description
S46.	Development in flood hazard areas	The potential for flood-related impacts to health, safety, and property may be reduced by limiting development in flood-prone areas.
S48.	Floodplain mapping update	Coordinate with FEMA to update the Flood Insurance Rate Map (FIRM) floodplain boundaries for special flood hazard areas such as the Mission and Sycamore creek drainages and Area A near the Estero.
S50.	Sea level rise	Monitor, assess, and adapt to changes in stream and coastal flooding characteristics that may occur due to a global climate change induced rise in sea level.
S51.	Monitoring, Data collection, and analysis of sea level rise.	Develop the following data and analysis to support future sea level rise risk assessment, vulnerability analysis, and adaptation planning (Tide gauge, coastal bluff monitoring, beach profiles, flooding and inundation)
S52.	Sea level rise risk assessment and vulnerability analysis	Conduct periodic sea level rise studies that provide risk analysis indicating probability and magnitude of future impacts to Santa Barbara due to sea level rise to support future adaptation planning.
S53.	Sea level rise adaptation	Identify policy options, costs, and consequences for addressing sea level rise issues
S54.	Shoreline Management Plan	Develop a comprehensive Shoreline Management Plan to identify, manage and to the extent feasible, mitigate or reduce climate change-induced sea level rise impacts upon public facilities, natural areas and private property along the City Shoreline.
S55.	Future inundation	Consider the following options in the development of adaptation plans for future permanent inundation effects
S60.	Polluted runoff	The City shall reduce health hazards associated with polluted runoff, including runoff which contains harmful bacteria and or viruses.
S61.	Sewer line erosion	The City shall support relocation of sewer lines which may be threatened by erosion.

This is a good "continued data" vision.

S52(b). Good. To become more detailed, it could "identify transects" to survey and regularly monitor. Also establishing a clear idea of how to define a cliff edge will be important here. Lidar data has a 1 meter horizontal resolution, meaning that a baseline or established cliff edge can fairly accurately be created, but that will not have the year-to-year accuracy to measure small erosion rates. Setting standard year-cliff edge baselines for the past will help with this, as it is unrealistic to look at cliff erosion on a scale of less than 50 years, unless one is looking at the widths of episodic failures. Following any major landslide, it would be amazing to create a new elevation model of the new cliff edge. GPS-enabled drone photography would be a really useful thing given that funding an airplane lidar flight and lidar-processing is probable infeasible due to monetary constraints.

S51(c). Consider using Revell's established transects for official survey transects for the purposes of tracking seasonal and long-term beach changes. There are a lot of assumptions that are currently made regarding the managed wide beaches of the waterfront areas, whether they are modeled as natural or assumed to be unchanged due to continual dredging operations; establishing data for this will be useful for future monitoring. A GIS digital elevation model for these beach profiles would be very useful for tracking changes. The waterfront takes an aerial photo at least once per year. If the photo is georeferenced and orthorectified (corrected for the warped output of a one-point panoramic-type photo), these could also be digitized to create a shoreline profile, but would need metadata to include the day of the photo and the tide level at the time of photo.

S51(d). Lidar is easily obtained; I would almost say "using detailed topographic mapping?" It could be mentioned that the California Coastal Conservancy's 2009-2011 Lidar project is currently the best baseline data available and is used by most mapping efforts (such as the Bren group's and Revell's) to assist with future efforts to compare baseline conditions.

It would be excellent to collaborate with Southern California coastal governments (or even statewide) and federal agencies to fund coastal lidar projects after major storms and at regular intervals. Committing funds to this without setting up a program first may be infeasible, but the City could put pressure on the state government to set up these disaster monitoring scenarios.

Policy S51 could stress the need for DATA more. It does not include policies for monitoring storms. A system for the collection and organization of data during and post-storm events would tremendously help with the ground-truthing of models such as the one from Revell et al. Data that should be collected and archived for large storm events should include photography (especially georeferenced, which is easily and generally automatically done with a smartphone), and records of depths of flooding. Setting up a method for compiling data electronically (especially in a GIS system) could help with scientific monitoring and modeling as well as with disaster plan debriefing, updating, and evaluating.

Policy S52 should be fleshed out to more specifically identify the knowledge needs (and desires) of policymakers. Additionally, the use of the word "consider" here seems like more of an imperative than the more general, normal use of "consider" in policy-level language. Also, setting up a way to integrate, incorporate, or build off of these periodic analyses will be useful. Consider establishing a more detailed framework for these assessments?maybe. The upside to establishing a set methodology means that the assessments could build on top of each other

and be compared (to look for increasing or decreasing projections of risk), but the downside is that it may keep the City from realizing that a different methodology could be more useful to providing relevant and useful data to the City.

S53. Good. S53(b) especially could be accomplished by methods similar to the LA infrastructure SLR assessment (or the Monterey survey) where actual asset managers estimate and consider the sensitivity of their structures (how might your facility be impacted by: wave damage, permanent inundation, flooding (of varying depths/velocities), etc.). "Consequences from sea level rise" seems ambiguous, but this could be more of "what's at risk"? Identifying some major utilities to be concerned about here would be useful, especially including those facilities outside of the City's direct control (electricity, road maintenance/emergency repairs like hwy 101).

S53(c). This policy is very vague. To definitively address SLR vulnerability, a policy closer to "incentivize private property owners along the waterfront to employ techniques for structural adaptation"?Really a policy that emphasizes creativity would be good, and finding a way to increase natural protection from storms (coastal and not). This is where creative alternatives to setbacks would be useful; in-lieu fees could allow the City to build up a disaster preparedness and/or response fund. Remember that the big problems will be storm flooding?and wave impacts for those assets located very much on the coast).

S54. This policy is good?stressing the output of data would be useful: defining, identifying and delineating the geographic extents of "public facilities" especially. Is this policy specific to include only beach and beachward geographies? All "coastal issues" listed here are sand and beach erosion related. Lacking is language addressing Stearns Wharf or the Harbor area. The only way that "public facilities" are being addressed in this policy would be through "protection/restoration of natural sand transport and sand supply replenishment projects."

Consider supporting multi-hazard and multi-jurisdictional projects. "Sensitivity" could encompass a location or facility's ability to respond to any hazard. Including sea level rise in the County's Multi-Jurisdictional Hazard Mitigation Plan may help frame these hazards in conjunction with other City (and Countywide) hazards. Two future directions include combining non-coastal flooding projections with SLR projections. Downscaled data from SBA CEVA project may be useful for this purpose in the near-term. Second would to be include site-specific protection measures currently in place into analysis of sea level rise.

The only major impacts to the human population of the City regarding future inundation (S55) are projected to occur between 0.93 to 1.67 m of inundation (2100 medium and maximum projections from NRC, 2012)?these values would increase the inland extent of smaller storms.

G.1 Additional Policy Thoughts

The City will promote a policy of planned retreat to minimize risks presented by coastal hazards including sea level rise. Planned retreat will implement a staged avoidance of permanent development for sites designated at risk. This could include a pre-determined trigger at which point property owners would be required to remove building structures. Triggers could include: a given sea level rise threshold has been reached, 10 years prior to a projected sea level rise (this could be around 0.93 meters for Santa Barbara), or after significant damage has occurred on this property.

Upsides to early planning for this (setting a year to plan for retreat, but allowing for longer lifetimes if sea level rise does not keep up with projections) include saving money from disaster response and rebuilding efforts. Additionally, the restoration of these sites can increase one or more of the following: open space, recreational facilities, public access, habitat migration, or more. Downsides include: potential takings lawsuits, a patchwork of retreat parcels that does not contribute to overall City protection.

Understanding the dynamic beach changes and the effects of higher water levels on Santa Barbara's managed beaches will help with planning efforts. Santa Barbara's best retreat options for decreasing risk to its populations and infrastructure revolve around focusing on the

Consider creating or expanding a staff position for someone to gather, identify, and summarize all past and future consultant work relating to hazards that sea level rise may exacerbate: fluvial and coastal flooding and bluff erosion. This could be instead a part of the role of an established adaptations or hazards committee.