Public Interest Energy Research (PIER) Program
White Paper

# CITY OF SANTA BARBARA SEA-LEVEL RISE VULNERABILITY STUDY

A White Paper from the California Energy Commission's California Climate Change Center

Prepared for: California Energy Commission
Prepared by: University of California, Santa Cruz

JULY 2012

CEC-500-2012-039

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# PREFACE

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's PIER Program established the California Climate Change Center to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions.

For more information on the PIER Program, please visit the Energy Commission's website http://www.energy.ca.gov/research/index.html or contract the Energy Commission at (916) 327-1551.

# ABSTRACT

Cliff and bluff erosion, flooding of low-lying areas, and damage to shoreline infrastructure and development will continue to affect California's coastal communities in the decades ahead. Depending upon the rate of future sea-level rise, changes in wave energy, and coastal storm intensity and frequency, these hazards will be likely become more severe, with increasing risks to coastal communities. This study assesses the vulnerability of the City of Santa Barbara to future sea-level rise and related coastal hazards (by 2050 and 2100) based upon past events, shoreline topography, and exposure to sea-level rise and wave attack. It also evaluates the likely impacts of coastal hazards to specific areas of the City, analyzes their risks and the City's ability to respond, and recommends potential adaptation responses. By 2050, the risk of wave damage to shoreline development and infrastructure in Santa Barbara will be high. Options are limited and adaptive capacity will be moderate, with retreat being the most viable long-term option. By 2100, the risk will become very high. By 2050, flooding and inundation of low-lying coastal areas will present a moderate risk to the City by 2050, which will have a moderate capacity for adaptation. If the high sea levels projected by the State occur, this risk will become very high, and adaptive capacity will become low by 2100. Cliff erosion has been taking place for decades, and as this process continues or increases, additional public and private property in the Mesa area will be threatened. The risk of increased cliff erosion will be moderate by 2050 and very high by 2100. Because armoring is ineffective here and retreat necessitates the relocation of structures, adaptive capacity will be low. Inundation of beaches presents a low threat to the City by 2050 but a high threat by 2100. The City faces a dilemma: protect oceanfront development and infrastructure or remove barriers and let beaches migrate inland. By 2100 structures will have to be moved if beaches are to be maintained.

**Keywords:** adaptation, adaptive capacity, climate change, coastal cliff erosion, coastal hazards, coastal storm damage, flooding, inundation, risk assessment, sea-level rise, vulnerability assessment, wave climate

Please use the following citation for this paper:

Griggs, Gary, and Nicole L. Russell (University of California, Santa Cruz). 2012. ***City of Santa Barbara Sea-Level Rise Vulnerability Study.*** California Energy Commission. Publication number: CEC-500-2012-039.

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# Objectives

Sea level is rising, and over time it will progressively threaten California's coastal communities. This paper is intended as an initial assessment of the vulnerability of the City of Santa Barbara to future sea-level rise and related coastal hazards. The first objective is to provide some background information about sea-level rise and to explain the factors that affect sea level globally and locally, including what is known about the recent history of changes in sea level along the California coast. The second objective is to present the likely sea-level rise projections (or scenarios) for the decades ahead and the general hazards that can be expected as a result of these projected changes. The third objective is to assess the vulnerability of the City of Santa Barbara to future sea-level rise based upon past events, its elevation and topography, and the exposure of its coastline areas to sea-level rise and wave attack. The fourth and final objective is to describe and evaluate the likely impacts of future sea-level rise on specific areas of the City, to analyze the risks that are posed by these hazards and the City's ability to respond to them, and to recommend potential adaptation responses for reducing the exposure to future risk from these hazards.

This assessment is part of a study that is funded by the Public Interest Environmental Research Program of the California Energy Commission. The study includes the development of a Guide for California's Coastal Communities about Adaption to Sea-Level Rise.

# Section 1: An Introduction to Climate Change and Sea-Level Rise

Scientific consensus, based upon an overwhelming body of evidence, indicates that global climate is changing and that it is caused in large part by human activities. Unless urgent action is taken at all levels of government to both mitigate and adapt to climate change, California and the rest of the nation and world will experience increasingly serious and damaging physical, ecological, and economic effects in the decades ahead.

Society's need to cope with changing climate and environmental conditions is not new. People have been adjusting to the Earth's environment since the dawn of civilization. Our growing awareness that the Earth's climate is changing, and that we are facing novel future climatic conditions that will interact with and compound our current economic and environmental challenges, has created a sense of urgency for climate adaptation planning.

Climate change is shifting climatic conditions outside of the range of past human experience. While previous insight into coping with climate variability and extremes can provide some valuable lessons for adapting to climate change, there are important differences between coping with *variability* and planning for *climate change*. ***Climate variability*** includes the normal range of conditions in temperature, rainfall, and other climate factors that we can expect from one year to the next. ***Climate change*** pushes the climate system across thresholds, creating new or different conditions.

While uncertainty remains when it comes to determining the exact way that climate change will affect California, uncertainty should not result in paralysis or a lack of action. Planning for climate change is fundamentally a risk management strategy, like an insurance policy, against an uncertain future. Managing these risks involves using the best available science to understand the likelihood of climate impacts and their associated consequences, and then selecting and implementing the most effective response options.

*America's Climate Choices* (National Research Council 2011) is a new report that includes a series of recommendations for responding to the risks that climate change poses to human activities. The Committee on America's Climate Choices' Vice-Chair, William Chameides, Dean of the Nicholas School of the Environment at Duke University, said of climate change, "We have enough of the picture to know that the time has come to act. When the river is rising and you're worried about a flood, you don't wait to act because you don't know how high the water will rise. You get out the sandbags and develop an evacuation plan. The climate is warming and there are major risks associated with it. America's climate choice is about deciding what to do about risk. And it's important for us to understand that doing nothing is a choice. It's a choice to live with greater and greater risk."

Global sea-level rise is the most obvious manifestation of climate change in the oceans. It is an issue that will have far-reaching consequences for California, given its high concentrations of people and developments along the coast. Sea-level rise will gradually affect and threaten coastal communities and infrastructure through an increased frequency of flooding and gradual inundation, increased rates of cliff, bluff, and dune, erosion, as well as progressive loss of beaches, with associated economic losses. *Inundation,* as opposed to *short-term flooding,* is a virtually permanent condition. This will affect coastal development, including homes and businesses; transportation facilities; electric utility systems and power plants; wastewater treatment plants; outfalls and storm water systems; ports and harbors; recreational facilities; and large wetland areas.

According to a recent report by the California Climate Change Center, nearly one-half million people in California—as well as hundreds of miles of roads and railways, major ports and airports, power plants and wastewater treatment plants—are at risk from future coastal flooding and inundation. California also has the nation's largest ocean economy, valued to be about $47 billion/year (in 2005 dollars), of which the great majority is connected to coastal recreation and tourism, as well as shipping and ports (Kildow and Colgan 2005). Many of the facilities and much of the infrastructure that support these industries, as well as the State's many miles of public beaches, are within just a few feet of the present sea level.

Sea level is expected to rise significantly during this century due to global climate change. Change in sea level is not a new phenomenon, however. Long before the start of human history, global sea level fluctuated over a range of more than 100 meters due to changes in the volume of ocean water and in the configuration (volumes) of the ocean basins. The main additions to ocean water volume come from the thermal expansion of seawater as it warms and from the breakup and melting of ice caps and glaciers as the Earth's climate shifts from cool glacial periods to warm interglacial periods. The most important contributors to long-term climate fluctuations are those associated with regular and predictable changes in the Earth's orbit around the Sun, which have cycles of tens of thousands of years and have been taking place throughout Earth's history.

Our longest measured records of sea level changes, some of which extend back 150 years or longer, come from coastal tide gauges or water level recorders. The geologic record is much older than that, but it contains many uncertainties (Figure 1.1). Tide gauge records from coastlines around the world indicate that, on average, global sea level rose by about seven inches during the twentieth century (about 1.7 millimeters per year; Figure 1.1). Individual tide gauges track local sea levels, which are records of the relationship between the elevation of the sea surface and the adjacent land surface. However, local sea level can vary from place to place as a result of either the gradual, ongoing uplift or subsidence of land. In addition to the long-term effects of land motion on local sea level, there are also short-term effects from changing climate regimes, such as El Niño events and Pacific Decadal Oscillation (PDO) cycles, which affect wind and storm patterns and ocean temperature (discussed later in the paper).

For the locations where land is rising, the rate of sea-level rise may be outpaced by the rate of coastal uplift. For example, at Crescent City, along the northern California coast, the local NOAA (National Oceanic and Atmospheric Administration) tide gauge records show a drop in sea level of two inches (or 0.65 millimeters [mm]/year) since 1933, when the gauge was first installed (Figure 1.2). The northern California and southern Oregon coasts are both undergoing uplift due to tectonic activity, which currently proceeds in those locations by a rate that is greater than the rate of global sea-level rise. However, the far north coast is the only place along California's shoreline where sea level is currently dropping relative to the land surface.

Several satellites that are capable of precisely measuring the level of the ocean from space were launched beginning in 1992. To date, the 18 years of data that have been collected are free of the effects of vertical land movements that can affect tide gauge measurements. They indicate that the average global rate of sea-level rise has increased to a little more than three millimeters per year between 1993 and 2010 (Figure 1.3).

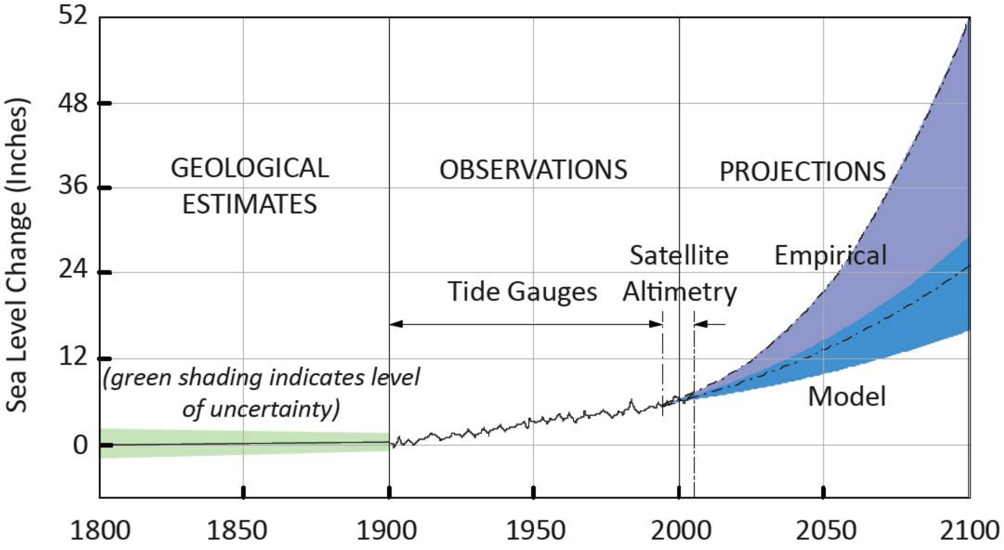


**Figure 1.1: Geologic and Recent Average Sea-level Rise Histories and Predictions. These are based on (a) geological estimates (from Antarctic and Greenland ice cores), (b) observations from global tide gauges and more recent satellite measurements, and (c) projections for the future, based on both climate models and empirical relationships between global atmospheric temperatures and sea level.**

Source: Modified from Shum and Kuo 2011

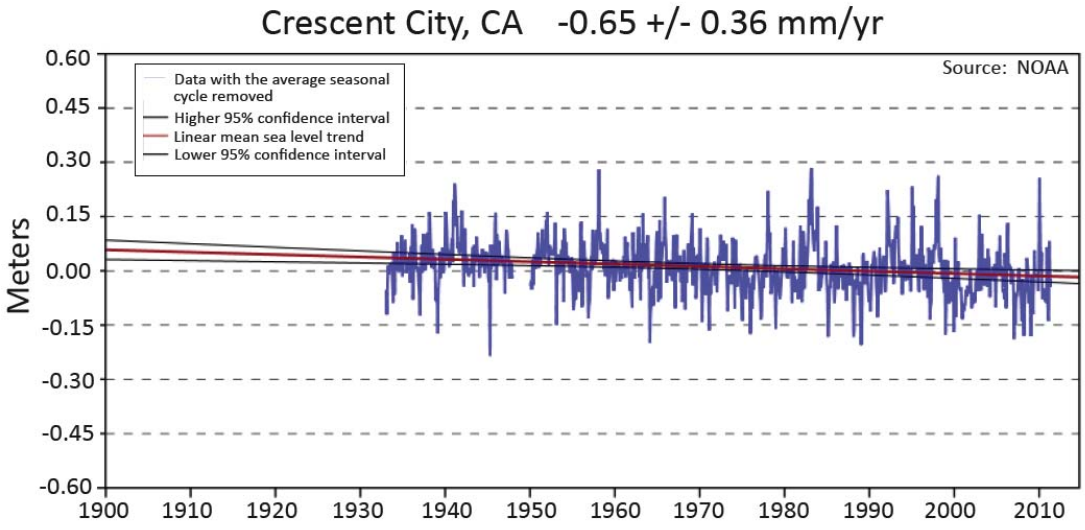


**Figure 1.2: Tide Gauge Record from Crescent City, Showing Long-term Drop in Local Sea Level Due to Uplift of the Coastline**

Researchers around the world are examining historical and modern data and using different approaches in order to make the best possible estimates of future sea levels for the decades ahead. There is much at stake for many coastal states and nations, including the high probability of the complete submergence of some island nations, such as the Maldives, displacement of millions of people in the case of Bangladesh, and the inundation of coastal cities and infrastructure, such as the San Francisco and Oakland international airports in California.

Sea-level rise has taken place since the last Ice Age ended, about 20,000 years ago. Although sea-level rise has been fairly gradual for the past several thousand years, rates began to increase around the year 1900. Sea level rose by an average of about eight inches along California's 1,100-mile coastline during the past 100 years (from NOAA tide gauges: http://tidesandcurrents.noaa.gov/geo.shtml), contributing to progressive shoreline retreat and the erosion of coastal cliffs, bluffs, and dunes.

The most recent assessments and climate models of future sea-level rise predict that both the rate of sea-level rise and the total change in sea level for this century may increase substantially above those of recent history. These projections are based upon new research findings of the last several years that suggest that previous estimates have probably been too low (Vermeer and Rahmstorf 2009). Recent research and climate change analyses indicate that the rate of sea-level rise will likely accelerate during the coming decades as ocean water continues to warm and expand, and as the ice sheets and glaciers of Greenland and West Antarctica break up more rapidly than they were previously anticipated to do.

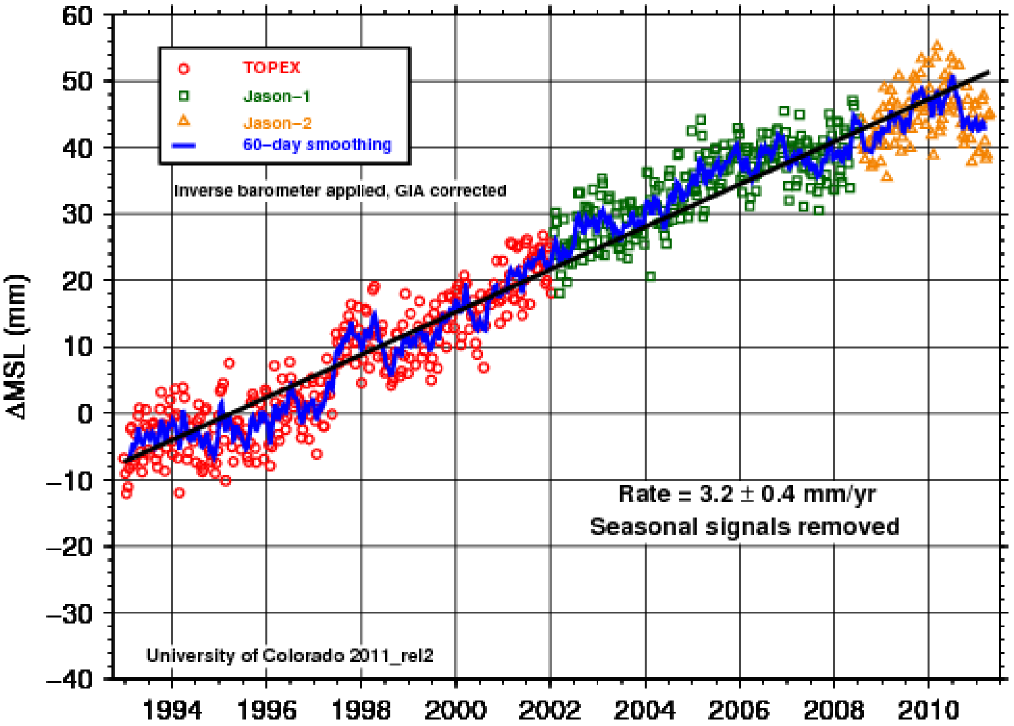


**Figure 1.3: Global Average Sea-level Rise as Measured by Satellite Altimetry from 1993–2011. Red, green, and orange symbols correspond to three different satellites. The data have been corrected for atmospheric pressure differences, seasonal differences, and isostatic adjustments. The vertical axis shows the change in mean global sea level.**

Source: http://sealevel.colorado.edu/

Perhaps most important, continued sea-level rise would exacerbate the effects of storm surge, large waves, and high tides in the future. If Santa Barbara and California's other coastal communities are to avoid or lessen the negative effects of sea-level rise and other associated climate changes, they should begin to adapt or respond now to the anticipated future conditions.

## 1.1 Awareness and Attitudes About Climate Change and Sea-Level Rise Among Planners and Managers

Several years ago, California's coastal cities and counties were surveyed about their awareness and attitudes about climate change as part of a California Energy Commission-funded study. Although it was completed in 2006, the responses to this survey should nonetheless provide a useful perspective for all coastal planners and managers today (Moser 2007; for complete results see Moser and Tribbia 2007).

About half of the 299 city and county staff responded, and 90 percent of the cities and counties provided input. When asked about their attitudes toward preparing for the impacts of global warming, over two-thirds of the respondents indicated that they were ready to prepare for the most likely climate-change scenario based upon the best available scientific information. The remaining third responded with the following: they wanted leadership from the top; they already had too much on their plates and could not deal with [climate change issues]; or they would rather wait to act until they had improved information.

While the vast majority of the respondents felt that they were "moderately well" informed about climate change, further questioning indicated that they got most of their information from newspapers and television news.

By the work of Moser and Tribbia, as well as the work of this study, it seems as though the most important types of information that coastal managers need and desire are vulnerability assessments for their communities. They want to know what will be most at risk in the future. By identifying what is most vulnerable, coastal managers can gain a clear sense of what they can do to in order to reduce the possible future impacts of sea-level rise. Coastal managers also expressed their desire for specific information by asking the following questions: "How far back [from the shoreline] do I have to tell people they have to build, and how does sea-level rise translate into a [cliff erosion or beach] retreat rate?"

Planners and managers do not need data alone; they also need to know how to use it. They want to know what other communities have done to adapt (Moser 2007). Local government planning staff usually use maps, geographical information systems (GIS), and to a far lesser extent, sophisticated analytical or forecasting tools. The clear message from those staff members who responded to the questionnaire is that agency staff members who do not know how to integrate technical scientific models and projections into their daily decision-making are unlikely to use them effectively. Thus, Moser recommends that the scientific community translate technical data into practical information by using formats that are already recognized by staff. With this in mind, we hope that the following sections will prove to be useful for Santa Barbara's coastal planners, managers, and decision-makers.

## 1.2 Recent Rates of Sea-Level Rise in California

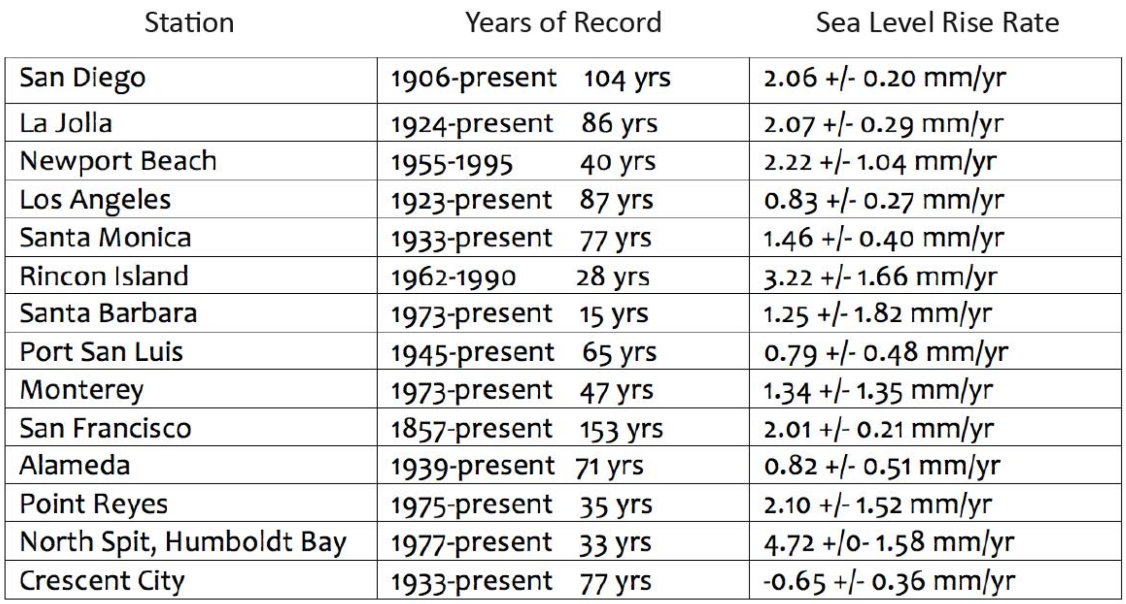
Rates of sea-level rise are region-specific because long-term land motion (i.e., uplift or subsidence) influences sea level at individual locations. In California, sea level has been measured historically at 14 different tide gauge stations that extend from San Diego to Crescent City, although two of these stations were discontinued during the 1990s (Table 1.1). Eight of the stations have recorded at least 50 years of data, and the oldest station, at San Francisco, has provided records since 1857.

Local sea-level rise rates at 10 of the 12 stations that cover the 800 miles from San Diego to Point Reyes vary from each other by surprisingly little, from 3.1 to 8.3 inches per century (or 0.75 to 2.10 millimeters per year). There are significant year-to-year variations, however. For example, a close look at the San Francisco tide gauge at Fort Point, near the Golden Gate Bridge, reveals the clear signature of large El Niño events that have affected the coastline at various points in the past century (Figure 1.4). Sea levels along the entire California coast have been elevated for months at a time during these events.

During the large El Niño event of 1983, high water level at the Golden Gate Bridge reached 8.87 ft., which is 1.77 ft. higher than predicted and the highest in more than a century of record-keeping. Sea level in Los Angeles that year was also the highest in 60 years of tide gauge history (7.96 ft., which is 1.06 ft. above predicted), as it was in San Diego (8.35 ft., which is 0.95 ft. above predicted, the highest in the 77-year history of that station). In addition to causing these extreme tides, the 1997–98 El Niño also led to sustained periods of elevated sea levels.

The State's two northernmost stations record the complex land motion along the northern California coast just offshore of Cape Mendocino where three large tectonic plates come together. At Humboldt Bay's North Spit, sea level is rising by 18.6 inches per century (4.73 millimeters per year), the highest rate in California (Figure 1.5). Just 80 miles north of Humboldt Bay, sea level is *dropping* relative to the coastline by 2.5 inches per century (0.65 millimeters per year; Figure 1.2) at Crescent City. The shoreline at Humboldt Bay is subsiding; whereas, Crescent City's coastline is rising. As mentioned previously, the far north coast is the only place along the California's shoreline where sea level is dropping relative to the land surface.

**Table 1.1: Historic Sea-level Rise Rates from NOAA Tide Gauges along the California Coast. The values listed in column three include both the average trend of sea-level rise and a 95% confidence interval (+ or - value). A discussion of the Santa Barbara tide gauge record is included in Section 2.**



| Station | Years of Record | Sea Level Rise Rate |
|---|---|---|
| San Diego | 1906-present 104 yrs | 2.06 +/- 0.20 mm/yr |
| La Jolla | 1924-present 86 yrs | 2.07 +/- 0.29 mm/yr |
| Newport Beach | 1955-1995 40 yrs | 2.22 +/- 1.04 mm/yr |
| Los Angeles | 1923-present 87 yrs | 0.83 +/- 0.27 mm/yr |
| Santa Monica | 1933-present 77 yrs | 1.46 +/- 0.40 mm/yr |
| Rincon Island | 1962-1990 28 yrs | 3.22 +/- 1.66 mm/yr |
| Santa Barbara | 1973-present 15 yrs | 1.25 +/- 1.82 mm/yr |
| Port San Luis | 1945-present 65 yrs | 0.79 +/- 0.48 mm/yr |
| Monterey | 1973-present 47 yrs | 1.34 +/- 1.35 mm/yr |
| San Francisco | 1857-present 153 yrs | 2.01 +/- 0.21 mm/yr |
| Alameda | 1939-present 71 yrs | 0.82 +/- 0.51 mm/yr |
| Point Reyes | 1975-present 35 yrs | 2.10 +/- 1.52 mm/yr |
| North Spit, Humboldt Bay | 1977-present 33 yrs | 4.72 +/0- 1.58 mm/yr |
| Crescent City | 1933-present 77 yrs | -0.65 +/- 0.36 mm/yr |

Historical extreme sea-level data (resulting from El Niño and other events) recorded by California's tide gauges can be downloaded from the NOAA websites.[1]

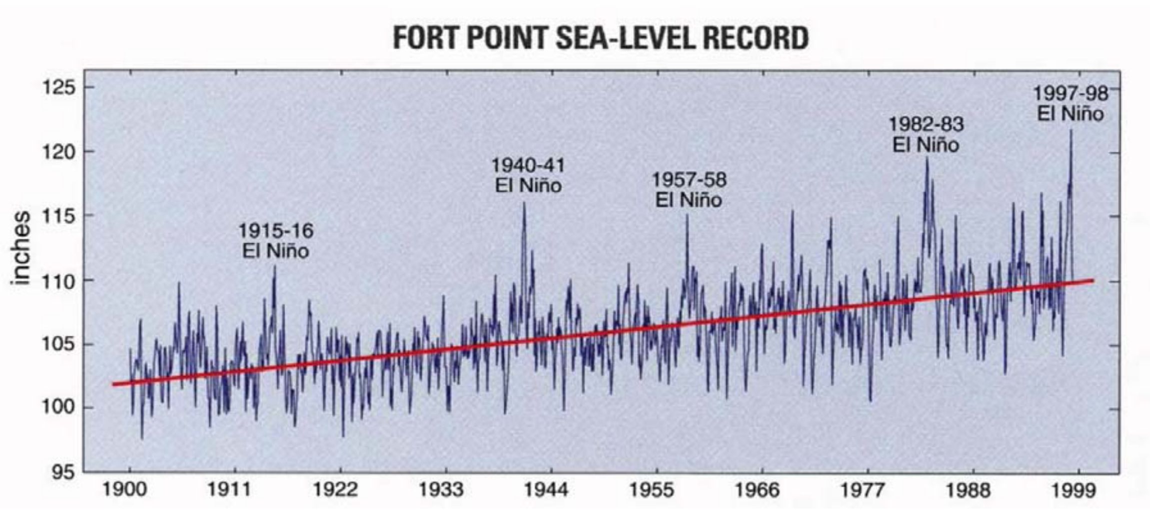


**Figure 1.4: Long-term Sea Level Record from Fort Point, San Francisco, Showing Extended Periods of Elevated Sea Level during Large El Niño Events**

Source: NOAA

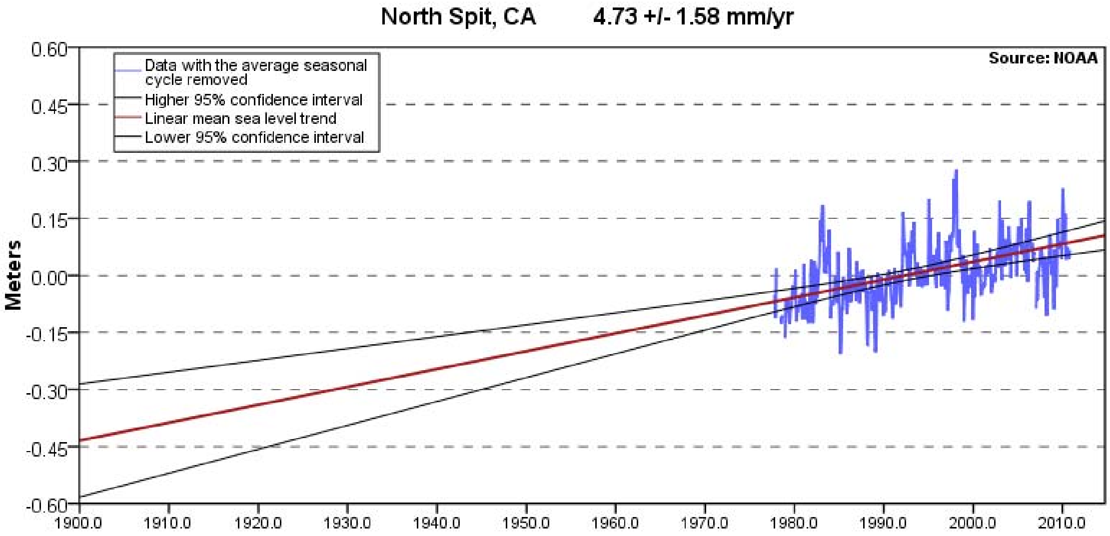


**Figure 1.5: Tide Gauge Record from the North Spit of Humboldt Bay, Showing an Average Sea-level Rise Rate of 4.73 mm/yr for the Period 1977–2006**

Source: NOAA

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[1] Sea Levels Online (http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml) and Historic Tide Data - Station Selection (http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic+Tide+Data)

When combined with high tides, short-term events such as El Niño storms that generate large storm waves will produce local water level increases along the shoreline that are far larger than the projected increases in global or regional sea-level rise for at least the next 40 or 50 years. The effects of high tides, storm waves, and a rising sea level are additive; they will all combine to increase coastal flooding, inundation, and erosion, with potentially significant damage to human development.

Because the relative rate of sea-level rise differs from one location to another along California's coastline, solutions for adaptation to sea-level rise are not "one size fits all." Thus, an individual community must concern itself with the relative rate of sea-level rise that is specific to its own region, while also accounting for local topography and development, as well as any other climate-related or coastal ocean hazards that may apply (i.e., the increasing frequency and height of storm waves; tsunamis).

## 1.3 Projecting Sea-Level Rise for the Decades Ahead

Global emissions of greenhouse gases have resulted in a general warming of the atmosphere, which in turn heats up and expands seawater. However, even when the atmosphere above the oceans is warm, it takes a long time for the oceans to warm and for sea levels to rise in response. This delay will result in sea levels that will continue to rise for centuries. Even if global emissions of greenhouse gases were to be stabilized today, thermal expansion of the world's oceans and the melting of ice sheets and glaciers on land would continue well after the year 2100. Therefore, infrastructure that is expected to have a long life and developments that are considered to be permanent will be forced to deal with the effects of sea-level rise for many decades to come.

There are several different approaches that are being used to project future sea-level rise, and climate scientists from universities, research institutions, and government agencies worldwide are engaged in studies of this issue. The Intergovernmental Panel on Climate Change (IPCC) is an international group that prepares regular updates about the state of knowledge regarding sea-level rise. The most recent IPCC report extrapolates sea level to the future by using different greenhouse gas emissions scenarios and various climate models to generate average global sea level values for 2030, 2050, and 2100 (Figures 1.1 and 1.6).

Vermeer and Rahmstorf (2009) use a semi-empirical relationship to relate global sea-level rise to global mean surface temperature. They propose that the rate of sea-level rise is roughly proportional to the amount of warming of the atmosphere (caused by human activity) above the temperatures that existed prior to the Industrial Revolution. This relationship is relatively straightforward and understandable: as atmospheric temperatures increase, there will be a gradual warming of the oceans with a corresponding expansion of seawater. A warming atmosphere will also lead to the progressive melting and retreat of glaciers, ice caps, and ice shelves, which will contribute to a gradual rise in sea level.

The California Ocean Protection Council and the Coast and Ocean Climate Action Team (CO-CAT), which consist of representatives from 15 different State agencies that all have some responsibility or authority regarding climate and sea level issues, have adopted sea-level rise projections for the decades ahead. CO-CAT uses Vermeer and Rahmstorf's projected scenarios for 2030, 2050, 2070, and 2100 (Table 1.2). The range in values for projected sea-level rise reflects different greenhouse gas emissions scenarios.

As sea-level rise is projected for the relatively distant future, the low and high values diverge. For example, predictions for 2030 differ from each other by very little: 4 to 8 inches (13 to 21 cm) above the sea level of the year 2000, with an average value of 7 inches. This is nearly equal to the total sea-level rise over the past century. By 2050, global sea level could rise by 10 to 17 inches (26 to 43 cm), with an average value of 14 inches (36 cm). By the year 2100, values for sea-level rise diverge significantly due to differences in greenhouse gas emissions scenarios. Table 1 includes Low, Medium, and High scenarios, and each of these includes a range and an average value. By the end of this century, the projected increases could add from 31 to 69 inches (78 to 176 cm) to the global sea level of the year 2000 (Cayan et al. 2006; Figure 1.6).

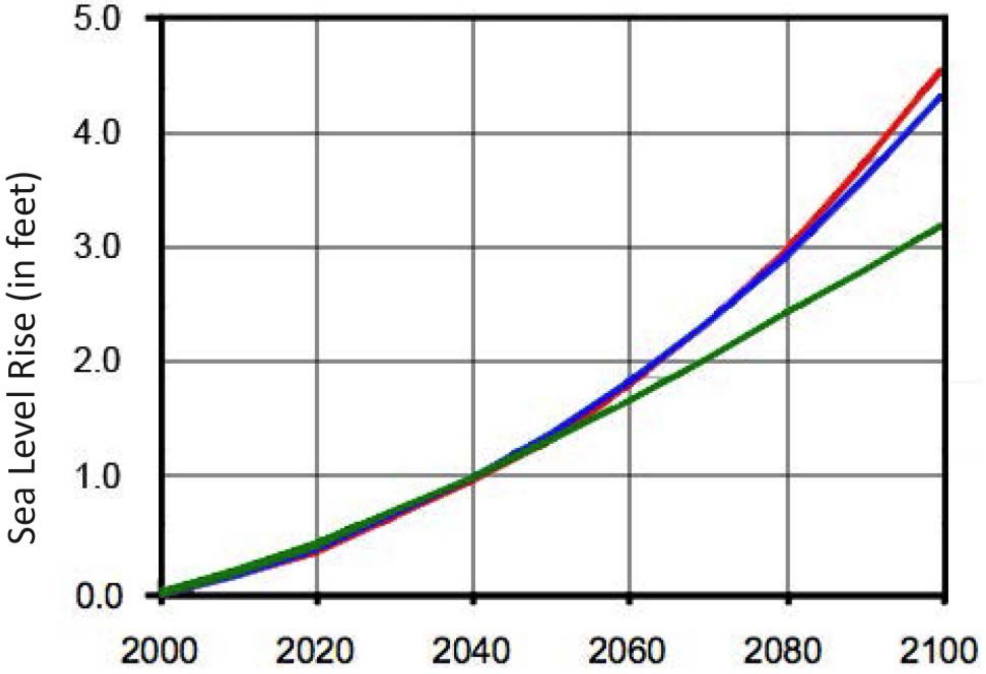

**Figure 1.6: Range of Projections for Future Average Global Sea-level Rise Based on Three Different Greenhouse Gas Emission Scenarios. Green = Low; Blue = Medium/High; Red = High. The vertical axis is predicted average global sea-level rise relative to the year 2000.**

Source: Adapted from Cayan et al. 2006

**Table 1.2: Sea-level Rise Projections Using the Year 2000 as the Baseline and Adopted by the California Ocean Protection Council**

| YEAR | | AVERAGE OF MODELS | RANGE OF MODELS |
|---|---|---|---|
| **2030** | | 7 inches (18 cm) | 5–8 in (13–21 cm) |
| **2050** | | 14 in (36 cm) | 10–17 in (26–43 cm) |
| **2070** | **Low** | 23 in (59 cm) | 17–27 in (43–70 cm) |
| | **Medium** | 24 in (62 cm) | 18–39 in (46–74 cm) |
| | **High** | 27 in (69 cm) | 20–32 in (51–81 cm) |
| **2100** | **Low** | 40 in (101 cm) | 31–50 in (78–128 cm) |
| | **Medium** | 47 in (121 cm) | 37–60 in (95–152 cm) |
| | **High** | 55 in (140 cm) | 43–69 in (110–176 cm) |

# Section 2: Vulnerability Assessment of the Santa Barbara Coastline to Future Sea-Level Rise and Related Coastal Hazards

In order to adapt to future change, a coastal community must have an understanding of ***vulnerability*** and ***risk***, as adaptation to sea-level rise is a risk management strategy for an uncertain future (also see **Appendix A. Definitions**). ***Vulnerability*** is the degree of exposure to a hazard. In this case, it is the degree of exposure to a relatively high sea level or to the combined effects of a relatively high sea level and storm waves that are larger than they have been in the recent past. On the other hand, ***risk*** combines the ***probability*** that a future event associated with sea-level rise (i.e., coastal flooding, inundation, or increased cliff erosion) is likely to occur with the ***magnitude*** or severity of the event.

Thus, a ***vulnerability assessment,*** which is necessary for informed adaptation, should include an evaluation of the degree of the community’s exposure to various coastal hazards. It should also include the magnitude of the damages or losses in the case of an event that elevates sea level significantly, such as a large El Niño or storm surge. In turn, ***adaptation*** is the adjustment of natural or human systems in response to actual or expected events and their effects, such that it minimizes harm or losses. A coastal community’s ***adaptive capacity*** is defined by its ability to respond to sea-level rise and its associated impacts, including the reduction or moderation of potential damages and coping with their expected or predicted consequences.

The changes that are now taking place in the ocean that have the potential to affect coastal communities like Santa Barbara are of several types, and each one needs to be evaluated, understood, and considered. The specific processes include:

A. Sea-Level Rise
B. Coastal Storm Damage and Erosion
C. Cliff Retreat
D. Shoreline or Beach Retreat
E. Runoff and Flooding
F. Tsunami Hazards

In addition to these individual processes, it is also important to understand that their effects can be cumulative, such that a combination will be more severe or damaging than any one individual impact. Examples include the combined effects of large storm waves, high tides, and **short-term** sea level increases that might be expected during large El Niño events. These will accelerate cliff erosion, erode beaches, flood low-lying shoreline areas, and damage oceanfront development or infrastructure. Santa Barbara has experienced these damaging events in the past and will experience them in the future, although they may someday occur more frequently than they presently do and be of greater magnitude than they are now. As mentioned earlier, these types of events pose the greatest threats to the Santa Barbara coastline for the **near-term future** (until about 2050).

Additionally, a continuing rise in local sea level over the **long-term** (between 2050–2100 and after 2100) will lead to short-term flooding and eventually to the permanent inundation of low-lying shoreline areas (with gradual narrowing of beaches) and damage to shoreline structures and infrastructure. The potential for a future increase in wave heights, when combined with a rising sea level, would increase or accelerate cliff, bluff, or beach retreat rates over the **short- to long-term.**

The consequences of any particular event might be physical/environmental, ecological, economic, or social. In this section, we include a general qualitative assessment of the risks to the City of Santa Barbara, with an emphasis on how anticipated future sea-level rise and a changing wave climate might affect public property and infrastructure, as well as private property along the City's coastline.

The Santa Barbara coastline is one part of a large system (a littoral cell) that is thought to extend upcoast around Point Conception to as far north as the Santa Maria River, and downcoast to Point Mugu. Sand reaches the beaches of Santa Barbara by way of large rivers (the Santa Maria and Santa Ynez), as well as small creeks, and to a lesser degree, from the erosion of Santa Barbara's coastal cliffs. The dominant waves from the northwest move the sand along the shoreline from west to east, as littoral drift. After sand is dredged out of the Santa Barbara, Ventura, and Channel Islands harbors, and after beaches are augmented by the large volumes of sand that are delivered by the Ventura and Santa Clara rivers, the littoral or beach sand is lost to the Hueneme and Mugu submarine canyons.

Much has been written about this stretch of coast over the years, covering the sources, transport, and sinks for sand, wave climate, impacts of harbor construction on the shoreline, beach changes, and erosion and protection. Instead of summarizing this large volume of research, we refer the reader to the following recent references: Orme et al. 2011; Barnard et al. 2009; Patsch and Griggs 2008; Revell and Griggs 2007; Patsch and Griggs 2006 a,b; Revell and Griggs 2006; Griggs et al. 2005.

## 2.1 Sea-Level Rise

Global sea level has risen gradually by a total of 350 feet since the last Ice Age ended, about 20,000 years ago. This change in sea level has largely determined the present location of the California coastline. However, it is the combined effects of large storm waves, especially those arriving during elevated sea levels (El Niño events) and high tides that have highly influenced the shape of the coastline and caused the most damage to coastal development over the past century.

Storm waves that are coincident with very high tides will continue to be the biggest threat to the Santa Barbara City coastline in the next several decades. The impacts of sea-level rise will likely begin to increase and become more noticeable during the second half of the twenty-first century than they have been in the recent past, particularly when combined with large El Niño-driven storm waves and high tides. A continuing rise in sea level will produce a range of hazards and impacts, including increasingly frequent coastal flooding, gradual inundation of low-lying beach and shoreline areas, continued and likely increased erosion of coastal cliffs and bluffs, and flooding at stream mouths, with associated damage to human development.

Each of these probable future sea-level rise impacts comes with a level of uncertainty because we do not yet understand with confidence: (1) how fast global sea level may rise in the future, (2) what the actual trend of local sea-level rise will be along the Santa Barbara coastline, and (3) whether a changing climate will generate an increase in wave heights.

Sea-level rise will gradually begin to cover low-lying areas, which will eventually include all of the shoreline and beach areas along the City coastline that are presently closest to sea level. Areas subject to inundation will reach progressively further inland as sea-level rise continues. For the purposes of this paper, ***flooding*** is considered to be the temporary covering of an area by water (whether by flood flow from a stream or from very high tides and ocean storm conditions), while ***inundation*** is the permanent covering of an area by water.

The greatest uncertainty in assessing future vulnerabilities lies in the estimation of the future times when impacts are most likely to occur. This section includes an assessment of low-lying areas and their potential for inundation at specific future times as a function of sea-level rise rates and shoreline topography (elevation). Accurate shoreline topography has been determined from aerial LiDAR (Light Detection and Ranging) data that was collected in October 1997, although the data only extends to about 1600 feet (500 meters) inland. The vulnerability assessment compares these elevations with a range of sea level elevations that are based upon rates of sea-level rise that are consistent with current models and other predictions.

Planning for any potential future sea level needs to consider the probability and the consequences of reaching a specific sea level at some future time and the ability to adapt to specific future sea levels, as well as the costs of adaptation.

### 2.1.1 The Record of Historic Sea Level Change along the Santa Barbara Coastline

Santa Barbara has one of NOAA's official tide gauges (water level recorders). Although it was established on the breakwater in 1973, the record is discontinuous due to two breakwater construction projects, which led to significant gaps in the data (Figure 2.1). Thus, while NOAA's website lists an average sea-level rise trend of 1.25 mm/yr (approximately 5 inches/100 years) for the gauge since 1973, the margin of error at the 95 percent confidence interval is very wide (+/- 1.82 mm/yr). This produces a large range of potential rates of future sea-level rise for Santa Barbara (-0.57 to 3.07 mm/yr), which makes it unwise to place a lot of confidence in the existing record and does not clearly show how the Santa Barbara coastline is tectonically changing relative to global sea level. In other words, we do not know for certain whether the coastline is rising, subsiding, or if it is stable. However, if the tide gauge remains stationary in the future, the record should become reliable and over time, it will provide a long-term indication of the rate of local sea-level rise along the City's shoreline**. It is recommended that all precautions be taken in order to protect the existing NOAA tide gauge at the breakwater from future construction or disturbance, such that a long-term record of local sea level change can be established.**

While satellite altimetry indicates an overall increase in the average rate of global sea-level rise over the past 16 years, the Western Pacific has risen by a rate that is *higher* than the global average rate. In contrast, the Eastern Pacific (including the ocean off of the coast of California), has leveled off and *dropped* slightly during the same time period (Figure 2.2). Nearly all of California's tide gauges confirm this recent satellite observation. The reason for this recent change is not completely understood. Some possible causes include a difference in water temperatures on opposite sides of the Pacific (with coastal upwelling off of the coast of California bringing relatively cool dense water to the surface and thus lowering sea level slightly), or the movement of warm surface waters toward the western Pacific by equatorial currents, or some other phenomenon. Recent predictions suggest that this short-term trend is about to change with a switch from the current, warm PDO phase to a cool PDO phase (Figure 2.3), which coincides with downwelling along the West Coast. This may lead to a reversal of the differential in sea level-rise rates across the Pacific and to an increase in the rate of sea-level rise along the west coast (Bromirski et al. 2011). Thus, although it appears from the Santa Barbara tide gauge record (and from other tide gauge records along California's coast) that sea level has dropped for the last decade or so, it is important to consider the long-term trend and the changes to be expected for the near future.

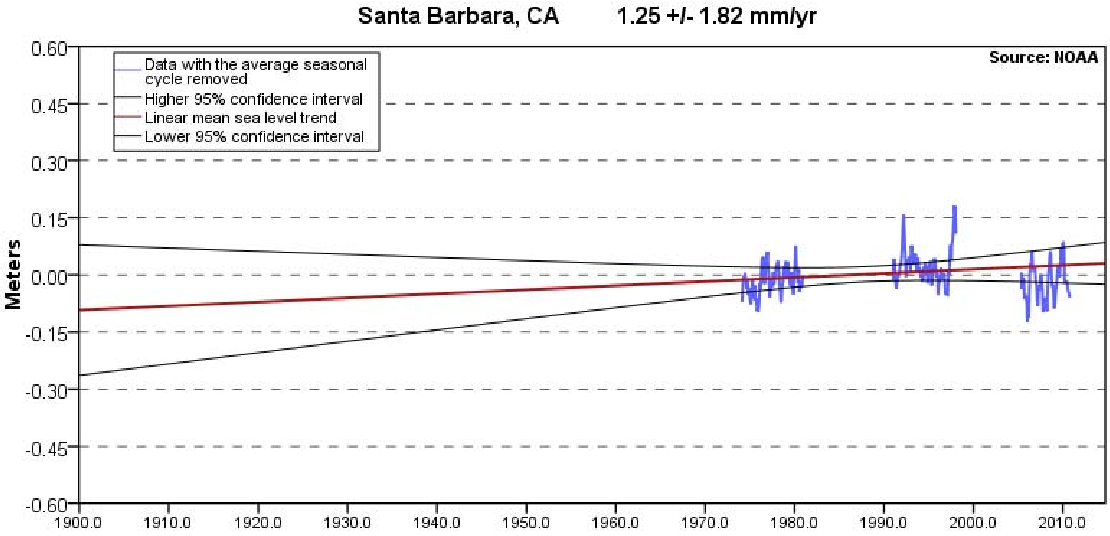

**Figure 2.1: Sea Level Record from Santa Barbara Tide Gauge. Record is discontinuous due to several harbor construction projects, which required relocating the gauge.**

Source: NOAA

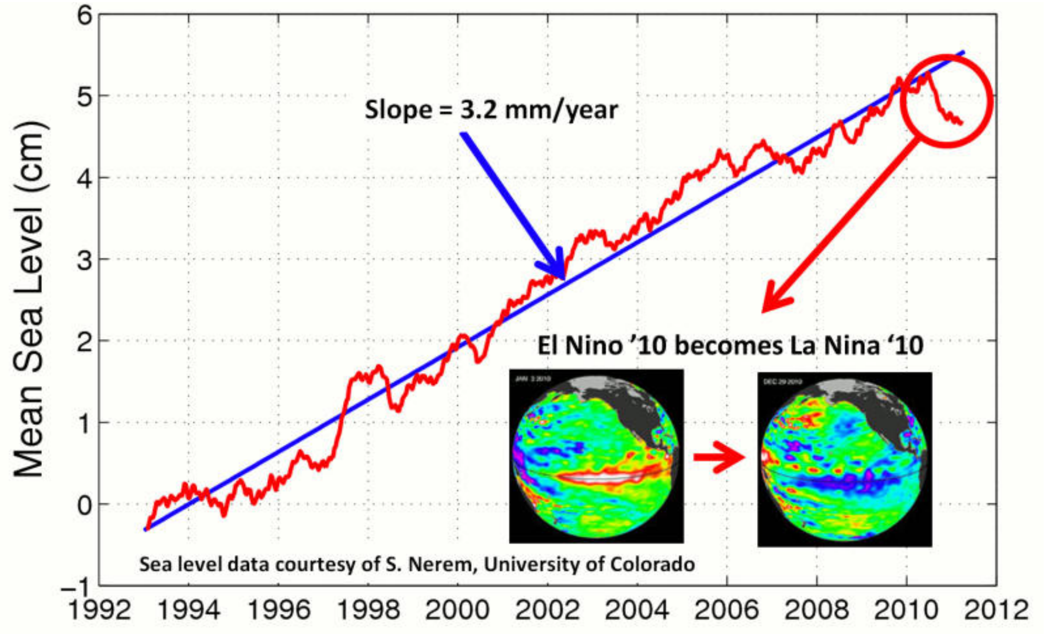

**Figure 2.2: Satellite Altimetry Indicates a Drop in Average Global Sea Level over the Past Year, but the Overall Long-term Trend is Clearly One of Rising Sea Level.**

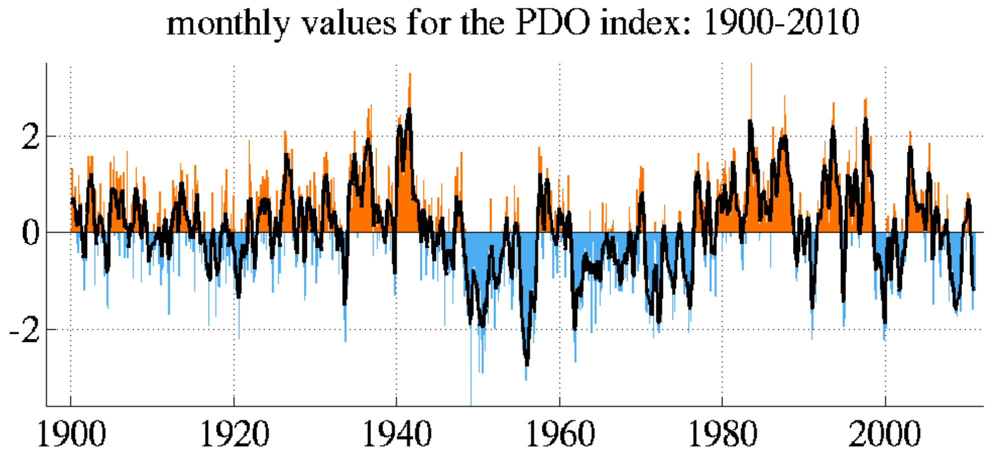

**Figure 2.3: Pacific Decadal Oscillation Index from 1900 to 2010. Red Indicates Warm Phases and Blue Indicates Cool Phases.**

Source: http://jisao.washington.edu/pdo/

### 2.1.2 Future Sea-Level Rise Projections and Their Effects

As mentioned previously, California's state agencies have adopted a set of interim values for the range in rates of sea-level rise that are projected through the year 2100 (Table 1.2), which are also recommended for adoption by local communities. Whether they are based upon Low, Medium, or High future greenhouse gas emission scenarios, projections for the year 2030 are practically uniform (average of 7 inches; range of 5–8 inches). By 2050, the values are still quite similar for all cases (average 14 inches; range 10–17 inches). However, the projections diverge significantly by the year 2100, with average values ranging from 40–-55 inches (total range of 31–69 inches). Any of these projections for 2100 would be much larger than the 7–8 inches of sea-level rise that have occurred along California's coast over the past century. As satellite data for global sea-level rise continue to be collected, and as the Santa Barbara tide gauge record is extended into the future, these values may need to be adjusted.

Where coastlines have not been altered by human activity, beaches and shorelines will naturally tend to migrate landward (or inland) as sea level gradually rises. On the other hand, where a barrier fixes the inland edge of a beach (whether it be a seawall, building, highway, or parking lot), the beach cannot move landward past the barrier with a rise in sea level. In the latter case, a beach will gradually be inundated or lost to the ocean unless there is some intervention, such as removing the back beach barrier. While adding sand to a beach (by dredge disposal or beach nourishment) may provide a short-term solution, this will be very expensive and cannot be sustained over the long-term if sea level rises significantly.

For the City of Santa Barbara, the future effects of sea-level rise will depend upon the magnitude of the increase in sea level, as well as the topography and presence of barriers along the City's shoreline area.

In July 2010, the California Ocean Protection Council authorized $2.75 million for NOAA to collect and process aerial LiDAR imagery and precise elevation data along the coast of California. This project will produce a high-resolution topographic map of California's entire coastline and it will serve as an update to the data that was collected before and after the 1997–1998 El Niño. However, those data were not available at the time that this assessment was completed. Instead, October 1997 LiDAR data have been used in this study for an evaluation of the flooding and inundation potential under several different future sea-level rise conditions (discussed in Section 3).

Good topographic data are essential for making accurate predictions of the effects of sea-level rise upon the coast, and this new statewide LiDAR dataset will serve as a record of California's current coastal elevations. Precise elevation data will allow resource managers and coastal community planners to assess and plan for the effects of sea-level rise and the chances of sudden inundation from storm surges and tsunamis (discussed later in this section). It will also contribute to wetland restoration planning, storm water and floodplain management, and coastal development planning. In addition, it will increase the efficacy of post-event responses (to large storms or floods, for example).

## 2.2 Coastal Storm Damage and Erosion

As sea level rises, there will be an increased number of extreme high water events per year, which tend to occur when high tides coincide with winter storms and their associated high wind, wave and beach run-up conditions. An increase in future coastal storm frequency and/or magnitude would likely increase rates of cliff retreat and cause potential damage to oceanfront property and development, whether it be private or public, including City infrastructure.

The effects of a rising sea level will be exacerbated by El Niño occurrences. Sea levels along the California coast often rise substantially for weeks at a time during these winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened. A compounding element as the sea level rises is the continued occurrence of winter North Pacific storms, which elevate water levels due to wind and barometric effects, especially during high tides. Some researchers believe that continued ocean warming and global climate change could cause an increase in the frequency and severity of El Niño events.

To further complicate matters, the coastlines of northern California, Oregon, and Washington have experienced increases in the intensities of winter storms and wave heights since 1975. Storlazzi and Wingfield (2005) completed an evaluation of changing wave conditions along the central California coast. They analyzed hourly wave data from eight different NOAA buoys that were deployed off of central California between Point Arguello (just north of Point Conception) and Cape Mendocino. They used 22 years of data from the early 1980s to 2002 to determine whether wave conditions may have changed over this period, and the significance of such changes.

For the period examined by Storlazzi and Wingfield, monthly significant wave heights (which is the average height of the highest one-third of the waves) increased by nearly one inch (2.5 cm)/year throughout the offshore area. In other words, average wave heights increased by about 1.4 feet (44 cm) over the 22-year period that was analyzed. This period was also characterized by a warm PDO cycle, which was dominated by an increased frequency of El Niño conditions. Storlazzi and Wingfield discovered that wave heights increase during El Niño months. It is not yet clear what these findings will mean for the long term.

Recently, Seymour (2011) analyzed changes in wave heights along the entire West Coast, using data from 26 offshore buoys for the years 1984 to 2007. He divided the data into two 12-year periods (1984–1995 and 1996–2007) and found a substantial increase in wave heights from the first to the second period. When examining the frequency of occurrence of mean wave heights in excess of 20 feet (6 meters) for 24 hours, Seymour discovered that the highest number of these events occurred off of the coast of Oregon in the second time period, followed by Washington and northern California. Under Seymour's criteria, there is no significant change in the frequency of occurrence of these large waves off of the coast of southern California.

However, when the wave height threshold is dropped from 20 feet to 16 feet (5 meters), there *is* a significant change in the frequency of occurrence of waves that are at least 16 feet high off of the coast of southern California. Between 1984 and 1995, there were only five events during which mean wave heights exceeded 16 feet for at least 24 hours, but there were 25 of these events between 1996–2007 (Figure 2.4). These data suggest that while the increase in wave heights (or storminess) is not as large off of the coast of southern California as it is off of the coast of northern California, the number of incidents of moderately large wave heights have occurred with increasing frequency in the second time period (the most recent decade). It will be important to determine how these trends might change or continue into the future. The combination of increased wave heights and increased sea levels will lead to increased rates of erosion at the coastline.

Ruggiero et al. (2010) have also reported significant increases in wave heights off of the coasts of Oregon and Washington over the past several decades. However, very recent work (Gemmrich et al. 2011) indicates that the trends detected by Ruggiero et al. are due to their analysis procedures and to changes in the wave measurement hardware (made by the buoy operators), and that no statistically significant wave height trends can be established for the study area. It will be important to continue to monitor waves off of the California coast to see what changes might take place over time.

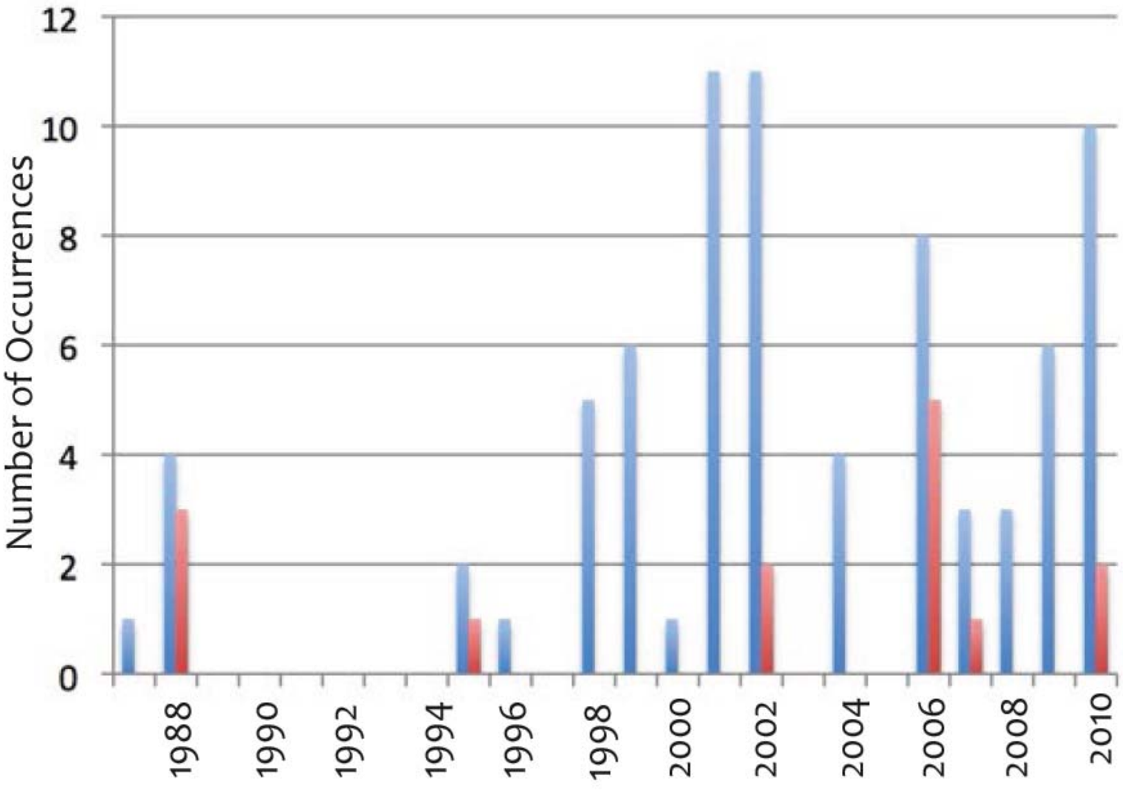

**Figure 2.4: Increasing Frequencies of Waves Exceeding 16 Feet in Height Off of the Coast of Southern California Since 1986 (South of Point Conception)**

Source: Coastal Data Information Program (CDIP)

## 2.3 Cliff Retreat

Both terrestrial and marine processes can drive sea cliff retreat, which can be delayed or accelerated by human actions. Wave impact can cause erosion at the base of a sea cliff, removing support for the overlying cliff face and triggering failure of the overlying materials. Where beaches are wide and waves seldom reach the bases of cliffs or bluffs, terrestrial processes, such as landsliding, runoff, and gullying, can dominate over wave erosion. Seawalls, revetments, and other armor structures can halt or slow coastal cliff or bluff erosion over the short to intermediate term.

Monterey Shale, capped by unconsolidated marine terrace deposits, makes up the majority of Santa Barbara's coastal cliffs. These materials are susceptible to erosion from waves as well as from terrestrial runoff, and they are also prone to landslides and slumps. The Monterey Shale has been deformed and tilted throughout this area, and in some places, its bedding dips (or tilts) toward the beach. This is known as a "dip slope condition." This is highly conducive to bluff failure, in which sliding occurs preferentially along exposed bedding planes (Figures 2.5 and 2.6).

**Figure 2.5: Dip Slope in the Monterey Shale along the Gaviota Coast, North of Santa Barbara**

Source: California Coastal Records Project

The cliffs at both ends of the City are experiencing active erosion and retreat. The changing position of the cliff edge was measured on historical aerial photographs in order to find average long-term erosion rates, which are reported to fall in the range of about 6 to 12 inches/year (Griggs et al. 2005). Hapke and Reid (2007) completed a statewide assessment that compares cliff edge position on aerial photographs from the 1930s with LiDAR data from 1998 (approximately a 70-year period) and obtained similar values: an average of about 4 inches to 18 inches/year for the Mesa area and just under 6 inches/year for the Clarke Estate/Cemetery cliffs.

The range in erosion rates is a product of local variations in bedrock strength, bedding plane orientation, and the effects of development and human interference, including protective cobbles, boulders, or riprap on the fronting beaches. However, the overall linear trend of the coastline along the Mesa indicates that long-term rates of cliff retreat are fairly uniform alongshore.

**Figure 2.6: Dip Slope in the Monterey Shale along the Shoreline Park Coastline, which Produces Conditions That Are Conducive to Slope Failure**

Source: California Coastal Records Project

Cliffs may appear to go unchanged for years until the right combination of groundwater saturation, sea level, wave attack, and/or seismic shaking causes episodic failure. The loss of two homes on the Mesa in 1978 to a large landslide shows how landsliding along the bluff edge can result in the nearly instantaneous loss of oceanfront property and structures. The winter of 1978 saw the first large El Niño event in years, and rainfall was heavy in Santa Barbara for several weeks prior to the slide. The Mesa failure was a typical rotational slump on a curved failure (rupture) surface, with a nearly vertical head scarp. Movement began on a February evening and destroyed two houses within a few hours. Over time, wave erosion at the base of the cliff will gradually remove loose material, and renewed slumping movement will likely occur in the future.

On January 25, 2008, Shoreline Park suffered a landslide that extended 70 feet along the cliff and moved the cliff edge back by 38 feet (Figure 2.7). Since its construction in the late 1960s, different sections of the cliff at the park have retreated intermittently. As erosion has occurred, walkways, picnic tables, and fencing have been relocated inland. Progressive retreat of the cliff fronting Shoreline Park can be expected to continue, possibly by an increased rate, in the future.

There are four miles of coastal cliffs within the City limits, including those extending from the City limits, west of Arroyo Burro Beach County Park, through Shoreline Drive and Shoreline Park on the west side, and those fronting the Clarke Estate and cemetery on the east side. Cliffs gradually decrease in height from about 150 feet, east and west of Arroyo Burro Beach Park, to about 100 feet at Meigs Road along the Mesa, to about 50 feet at Leadbetter Point. Cliffs at the Clarke Estate are over 50 feet in height, but they decline in elevation toward Butterfly Beach.

**Figure 2.7: January 2008 Landslide along the Cliff at Shoreline Park Moved the Cliff Edge Landward by as Much as 38 Feet and Eliminated a Portion of the Sidewalk**

Approximately 98 single-family homes and a few undeveloped parcels line the cliffs of the Mesa within the City limits. Existing homes along Cliff and Shoreline Drives and El Camino De La Luz are vulnerable to cliff erosion. These cliff top homes were constructed at different times, and current setbacks from the cliff edges vary. Some Shoreline Drive homes or their additions (such as decks, patios and other accessory structures) are located immediately adjacent to or within a few tens of feet of the cliff edge (Figures 2.8 and 2.9). Google Earth was used to measure distances from the cliff edge to homes along the Mesa. These range from about 35 to 300 feet, with an average of about 100 feet. The proximity of a large number of homes and their additions to the cliff edge, combined with the cliff's general instability and long-term retreat rates, results in a moderately high vulnerability to future cliff retreat and accelerated erosion due to a rising sea level and an increase in wave energy.

The cliffs that front the Clarke Estate and the adjacent cemetery are subject to ongoing failure through landsliding (Figure 2.10). Uninterrupted riprap was placed at the base of the bluff below the estate in the 1980s. This has reduced wave impact at the base of the bluff, but it does not seem to have halted the failure of overlying materials, which appears to result primarily from terrestrial processes. An old concrete seawall that was built years ago at the east end of the bluffs below the cemetery has gradually deteriorated, and riprap and some cliff-top retaining walls have been constructed in its place in an attempt to slow erosion. Many years ago, several groins were built in this area in order to trap littoral drift and to widen the beach, but these have also deteriorated over time and are no longer effective.

Average annual rates of cliff erosion in this area have been measured from historical aerial photographs, which show a rate of about 6 to 12 inches/year (Griggs et al. 2005; Hapke and Reid 2007). Along the Mesa, these rates can be expected to at least continue, and likely increase in the future as sea level rises and wave energy increases. A geotechnical firm has monitored the cliff edge by the cemetery since 1990 in order to provide advice about appropriate actions. Some of the gravesites that were once closest to the cliff edge have been moved back over time.

Figure 2.8: Structures along the Mesa That Are Virtually at the Cliff's Edge

Source: California Coastal Records Project

Figure 2.9: A Number of Homes along the Mesa Are within 50 Feet of the Cliff Edge

Source: California Coastal Records Project

**Figure 2.10: Active Cliff Erosion along the Clarke Estate and the Adjacent Cemetery**

Source: California Coastal Records Project

With average historic retreat rates of between 6 and 12 inches per year, City bluffs can be expected to retreat by at least 10–20 feet over the 20-year lifespan (by 2030) of *Plan Santa Barbara* and potentially by even more than that in places where hazards such as uncontrolled drainage, historic landslides, or adverse bedding planes exist (AMEC 2010). Six to 12 inches/year translates to about 45 to 90 feet of retreat by the year 2100. Although bluff retreat is episodic, this projected retreat rate could expose a number of existing oceanfront homes, accessory structures, and other developments to severe damage or destruction. Portions of the oceanfront walkways, trails, the playground and picnic areas, and two restrooms at Shoreline Park are located within 50 feet of the present cliff edge, and portions of the two parking lots are located within 100 feet of it.

PWA (2009) developed a model for predicting future bluff retreat by using the projected increase in the exposure of the base of a bluff to wave impact as sea level rises. This model (Figure 2.11) indicates that the Shoreline Park area is projected to retreat by 270 feet, while the Mesa is projected to retreat by 525 feet. These projections correspond to average erosion rates for the next 88 years that are 3 to 6 times higher in the Shoreline Park area and 6 to 12 times higher in the Mesa area than average erosion rates of historic times (6 to 12 inches/year). Retreat of 270 feet by 2100 would require an average erosion rate of 3 feet/year for the next 90 years, and losing 540 feet would require an average annual cliff erosion rate of 5.8 feet. This would threaten most of the cliff top homes, public roads, and utilities, and it would substantially reduce or potentially eliminate public amenities such as Shoreline Park and the Douglas Family Preserve. Increased coastal erosion could also affect the nearly four miles of coastal bluffs that front the Mesa and eastern Hope Ranch (Hope Ranch is not within the City's jurisdiction). When considering historic cliff retreat, projected future sea-level rise rates, the nature of cliff failure in this area (which is primarily driven by terrestrial processes) and the inherent uncertainties in any model, these accelerated erosion rates appear to be very high and need to be updated over time. **It is recommended that a cliff edge monitoring program be established with a set of surveyed transects that can be regularly re-measured in order to document and track rates of retreat along all sea cliffs within the City limits.**

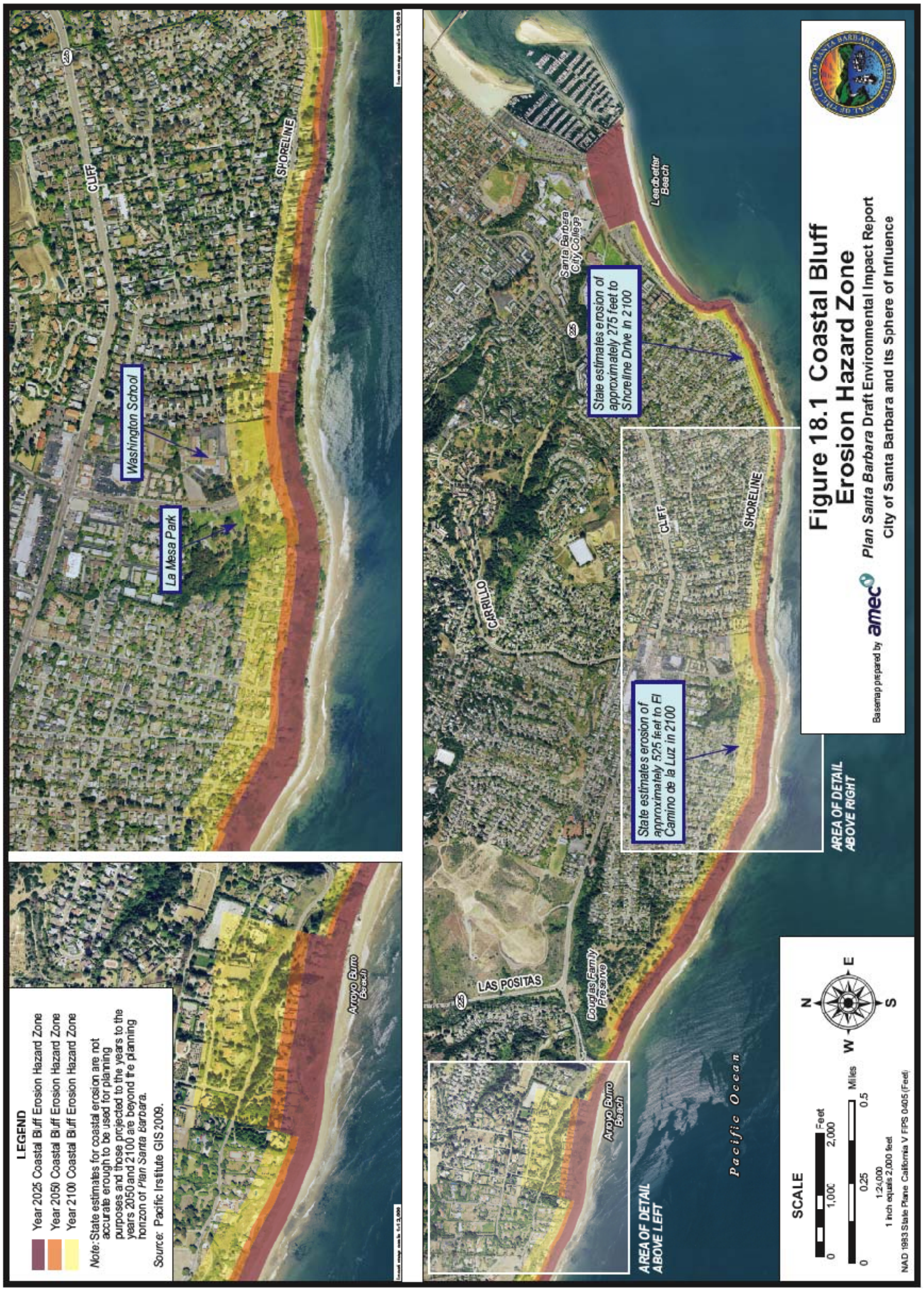

**Figure 2.11: Projected Future Cliff Erosion Lines on the Mesa for 2025, 2050, and 2100 from the Plan Santa Barbara Environmental Impact Report (EIR)**

There is an additional discussion of future cliff erosion in Section 3. With the exception of the Sea Ledge Lane revetment at the western edge of the City, there is no shoreline armoring along the Mesa area at present, although there are many Monterey Shale boulders at the base of the cliff that act like riprap in some places (Figure 2.12).

**Figure 2.12: Boulders and Cobbles of Monterey Shale Form Natural Riprap below the Mesa**

## 2.4 Shoreline or Beach Retreat

As sea level rises, the shoreline will gradually move landward. Within the City of Santa Barbara, this could lead to a gradual loss of the more than three miles of beaches that front low-lying coastal land, including Leadbetter Beach, its associated facilities and infrastructure, and East Beach and West Beach. Park facilities, parking lots, and Cabrillo Boulevard serve as back beach barriers to the City beaches, such that the beaches cannot retreat in response to a rising sea level.

The construction of the Santa Barbara Harbor breakwater (circa 1930) and the ongoing maintenance dredging and spoils disposal permanently altered much of the City’s beach area. Leadbetter Beach was created as littoral drift (sand) from the west was impounded (dammed) by the breakwater. The present sandy beach is fairly narrow and varies in width from about 50 to 175 feet. However, the former back beach area was gradually covered over with park facilities, parking lots, a road, a stadium, and a number of harbor-related buildings and infrastructure (see Figures 4.1, 4.2 and 4.3). In spite of this, West Beach is much wider now than it was during pre-harbor conditions because of the sheltering effect of the harbor breakwater. The beach that lies just east of the Harbor (toward East Beach) is affected by harbor dredge discharge, but it progressively decreases in width and artificiality from west to east.

Any narrowing or loss of these beaches (Leadbetter, West, and East beaches) would progressively expose public facilities such as the coastal bike trail, public parking lots, restrooms, and development at the Santa Barbara Harbor, Cabrillo Boulevard, Stearns Wharf, and the Cabrillo Bath House to periodic flooding and/or increased damage from wave action. Many of the City beaches and facilities already periodically experience moderate levels of damage from high tides and winter storms (Figure 2.13).

The entire City shoreline, including the Leadbetter Beach parking lot, City beaches, the coastal bike path, and the municipal wharf, sustained damage during the El Niño storms of 1983 (see Box Essay on the effects of the 1983 winter and Figures 2.14, 2.15, 2.16, and 2.17). Significant narrowing or erosion of these beaches could also impair or reduce recreational areas, with possible economic consequences. However, in the near-term years (until at least 2050) it is the large El Niño events with their elevated sea levels that will likely be the most hazardous to the shoreline when they are combined with high tides and storm waves.

It is important to keep in mind that the harbor breakwater and dredge disposal have significantly altered the Santa Barbara shoreline such that Leadbetter and West Beaches are no longer considered to be natural. As a result, it is somewhat uncertain how these beaches will respond to a gradual rise in sea level and a possible change in wave conditions. This will be discussed in Section 3's risk assessment.

The El Niño winter of 1983 affected the entire California coastline, from Crescent City in the north, to San Diego in the south. Elevated sea levels, plus a series of big storms that generated large waves that also happened to coincide with high tides, combined to produce the *highest* tides on record at many West Coast tide gages, causing over $200 million in damage along the State's coastline (in 2009 dollars). Thirty-three oceanfront homes were completely destroyed, over 3000 homes and businesses were damaged, and losses to public facilities and infrastructure were widespread.

Figure 2.13: Waves Overtopping West Cabrillo Boulevard in 1914

Figure 2.14: Beach Erosion Extended beneath the Santa Barbara Yacht Club in March 1983

Source: Santa Barbara News-Press

## Box Essay: Effects of the 1983 Winter on Santa Barbara, California

As a society, we tend to quickly forget past disasters, tragedies, and losses as we clean up and rebuild. Be that as it may, past disasters stand as evidence of events that can happen again in the future and as such, provide important information for city planning. As explained previously in this study, it is the severe El Niño events, such as those which occurred in 1983 and 1997–98, that will be the most damaging to the Santa Barbara coast in the near term (until at least 2050). In time, a changing climate and a rising sea level will increase the severity and frequency of coastal hazards and extreme events. It is useful to seek some perspective from the 1983 winter, as reported in the pages of the *News-Press* nearly 30 years ago, on March 2, 1983:

### Savage Surf Slams County Coast -

Santa Barbara News-Press - March 2, 1983.

"Monstrous surf, which one expert said was the biggest he's seen in more than 20 years here, ravaged the Santa Barbara coastline overnight, seriously damaging dozens of homes, closing Stearns Wharf, and turning the harbor into a debris-strewn wasteland."

"Clean-up crews worked around the clock, boat owners grabbed valuables from their vessels and beachfront dwellers boarded up windows in anticipation of another round of pounding breakers late this morning."

"Stearns Wharf suffered at least $100,000 damage as waves hammered away at pilings and planking...the structure, which has been closed indefinitely to the public, lost an estimated 20 pilings. The most serious damage occurred at the Moby Dick Restaurant, which caught the brunt of pounding waves. The restaurant sagged significantly toward the harbor [Figure 2.14], and Paul Nefstead (wharf manager) said further damage could result if high surf continues."

"At the harbor, a wave as high as a two-story building washed over the harbormaster's office at about 10:30 pm, flooding the building and forcing it to be evacuated. Both that office and the Santa Barbara Yacht Club (Figure 2.13) were seriously undermined by the force of the waves, which caused cars in nearby parking lots to tip over, a major gas leak and three small electrical fires. Several other businesses in the area were battered extensively by the surf, including Carter's bait and tackle shop."

"The Leadbetter Beach parking lot was destroyed, officers added."

"Along the Montecito waterfront, debris and rocks the size of basketballs that been pushed over the seawall by the pounding waves littered Chanel Drive in front of the

**Figure 2.15: Looking West at Erosion That Removed Part of the Leadbetter Beach Parking Lot during the 1983 El Niño**

## 2.5 Runoff and Flooding

Events such as flooding from severe storm events mostly reflect *climate variations* or *fluctuations.* For these types of events, we have good records, because the City of Santa Barbara has experienced them many times throughout its history. We therefore have a high degree of certainty that floods will occur again in the future. The uncertainty lies in predicting the future frequency and severity of these events due to changes in climate.

Climate change may increase both the frequency and severity of flooding from the City's creeks in several different ways. Changing weather patterns may lead to an increase in the concentration of winter rainfall and runoff, which would intensify both the frequency and depth of flooding. Increasingly dry summer conditions would raise the probability and magnitude of the Santa Ynez Mountains' wildland fires. The aftermath of these fires would include both increased runoff and increased sediment discharge from stripped watersheds, as well as creek channel obstruction from debris flows. Such conditions would amplify downstream flooding.

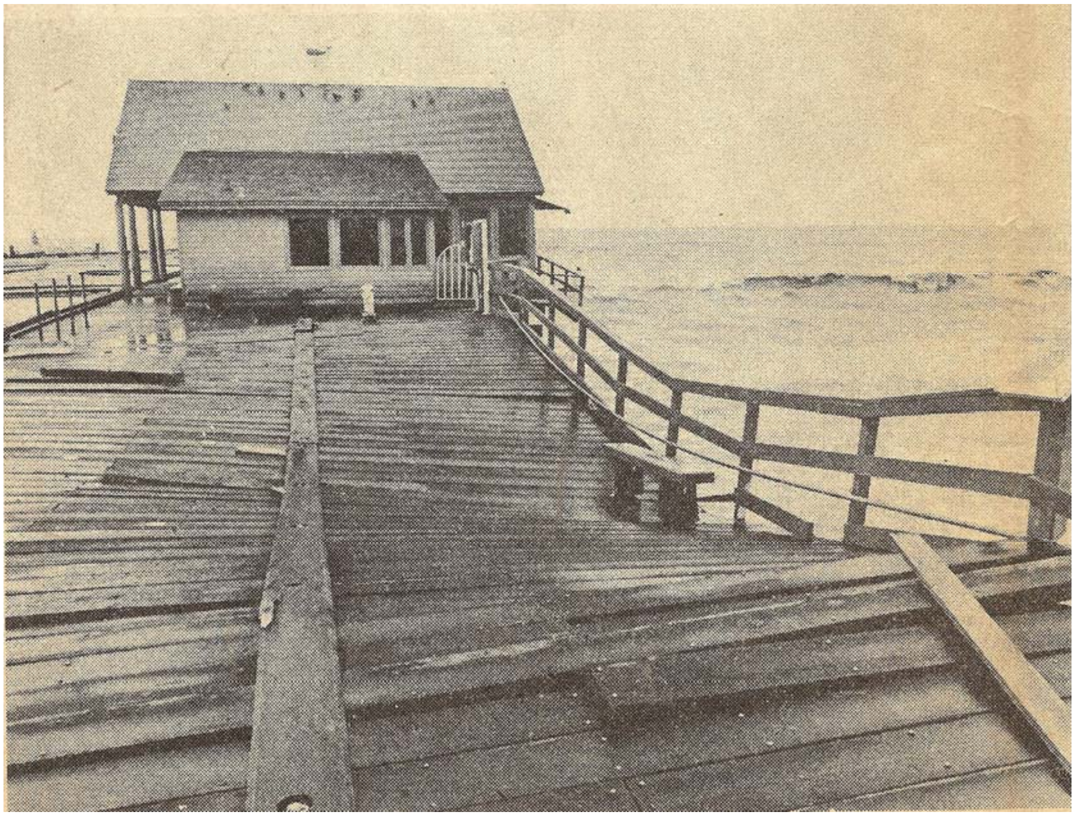

**Figure 2.16: The End of Stearns Wharf Sags from a Loss of Pilings in early March 1983 Due to Impacts of Large Waves at Times of High Tides and Elevated Sea Level**

Source: Santa Barbara News-Press

Backwater conditions at coastal drainages have been identified as important effects of global climate change (Plan Santa Barbara EIR). Where streams meet the coast, backwater conditions can occur as elevated sea levels (from high tides, storm surges, or over the long-term, from rising sea levels), preventing floodwaters from draining rapidly and causing streams to back up or slow down, which leads to upstream flooding. In the future, flooding could result from the increased heights of storm surges, increased tidal elevations, flood flows, and backwater flooding. In addition, the City of Santa Barbara has multiple small storm drains that empty onto area beaches, and they could also experience backwater conditions and localized flooding with an increase in sea level.

The Santa Barbara area has a long history of flooding, beginning with the widespread shoreline inundation that accompanied the nearly nonstop rains from November 1861 through January 1862. These storms were so severe that the Goleta Slough, once deep enough to accommodate ships, was filled in with the silt and debris that washed down from the mountains. Santa Barbara's *estero*, which generally covered the lower eastside during the winter months, was reported to have turned into a lake that stretched from Garden to Milpas and as far as Anapamu, leaving Olive Street (Canal Street in those days) as just a finger of land rising above the water. Other high spots, like the Gonzales adobe (between Laguna, Garden, Canon Perdido, and de la Guerra) temporarily resembled small islands.

**Figure 2.17: Palm Park, along Cabrillo Boulevard, Is Strewn with Debris, Including a Picnic Table That Was Carried in by Waves That Overtopped East Beach in March 1983.**

Source: Santa Barbara News-Press

It seems as though the first major storm and flood to be extensively recorded in photographs occurred on January 25, 1914, when a reported 9.36 inches of rain fell within 48 hours. The creeks that coursed through the City overtopped their banks, leaving behind extensive debris and damage (Figures 2.18 and 2.19).

Currently, flooding occurs during high tides and major storm events along Mission Creek, the Laguna Channel and Sycamore Creek on the City's Eastside, along Arroyo Burro Creek in the Upper State Street and Hitchcock Avenue areas, and along Modoc Road. Along the coast, backwater conditions can occur where elevated ocean levels prevent floodwaters from draining rapidly, leading to increased upstream flooding.

Figure 2.18: Southern Pacific Railroad Station Inundated with Mud Following Flooding in 1914

Figure 2.19: Mud Deposited at State and Yanonali Streets during Floods of 1914

The increased flooding that is associated with sea-level rise is a concern for low-lying communities across Santa Barbara County. Much of the City waterfront, lower reaches of downtown, and the lower Eastside are fewer than 10 feet above the historic mean sea level. Even the lowest projected sea level increases could adversely affect drainage and increase the risk of seawater flooding in these areas. The *Plan Santa Barbara (Plan SB)* EIR (AMEC 2010) includes a map that depicts both the 100-year coastal flood zone (using the year 2000 as a base) and the 100-year flood zone with 55 inches of sea-level rise (near the high end of sea-level rise projections for the year 2100, as adopted by the State; Figure 2.20). However, the map base is a Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM), and FIRMs have historically been based upon existing topographic maps, which often do not have precise elevation controls. As a result, we believe that there is significant uncertainty regarding the boundaries of the areas that are delineated on these maps as being subject to inundation under the conditions mentioned previously. While LiDAR can produce vertical elevations within six inches (which is a significant improvement over the FIRM's accuracy) there is no existing LiDAR data that extends inland by more than about 1600 feet from the shoreline for more precise elevation control than what is offered by the FIRM (Figures 2.21 and 2.22).

The *Plan SB* EIR map indicates that at present, a 100-year coastal flood would cover the Leadbetter Beach area, even reaching as far inland as Shoreline Drive in some places. To the west, the entire City beach, from the harbor to the end of East Beach, could be flooded, with run-up reaching Cabrillo Boulevard along virtually the entire City shoreline. As confirmation, the 1983 El Niño was accompanied by elevated sea levels, high tides, large waves, and storm surge, which eroded portions of the Leadbetter Beach park facilities, damaged the yacht club and harbormaster's office, and reached almost to Shoreline Drive (Figures 2.14, 2.15 and 2.16). Waves also carried debris to Cabrillo Boulevard at Palm Park (Figure 2.17). Thus, for present sea level conditions, the *Plan SB* EIR map appears to provide a reasonable estimate of the combined effects of El Niño, storm surge and wave run-up conditions.

However, adding a 100-year coastal storm on top of 55 inches of sea-level rise in the year 2100 moves the area of inundation by a considerable distance inland, according to the City EIR consultant (Figure 2.20). Due to the extent of the area that is projected to flood under these conditions in 2100, it is critical to determine the precise elevations throughout the area between the shoreline and the portion of the City that is shown on the *Plan SB* EIR map to be flood-prone.

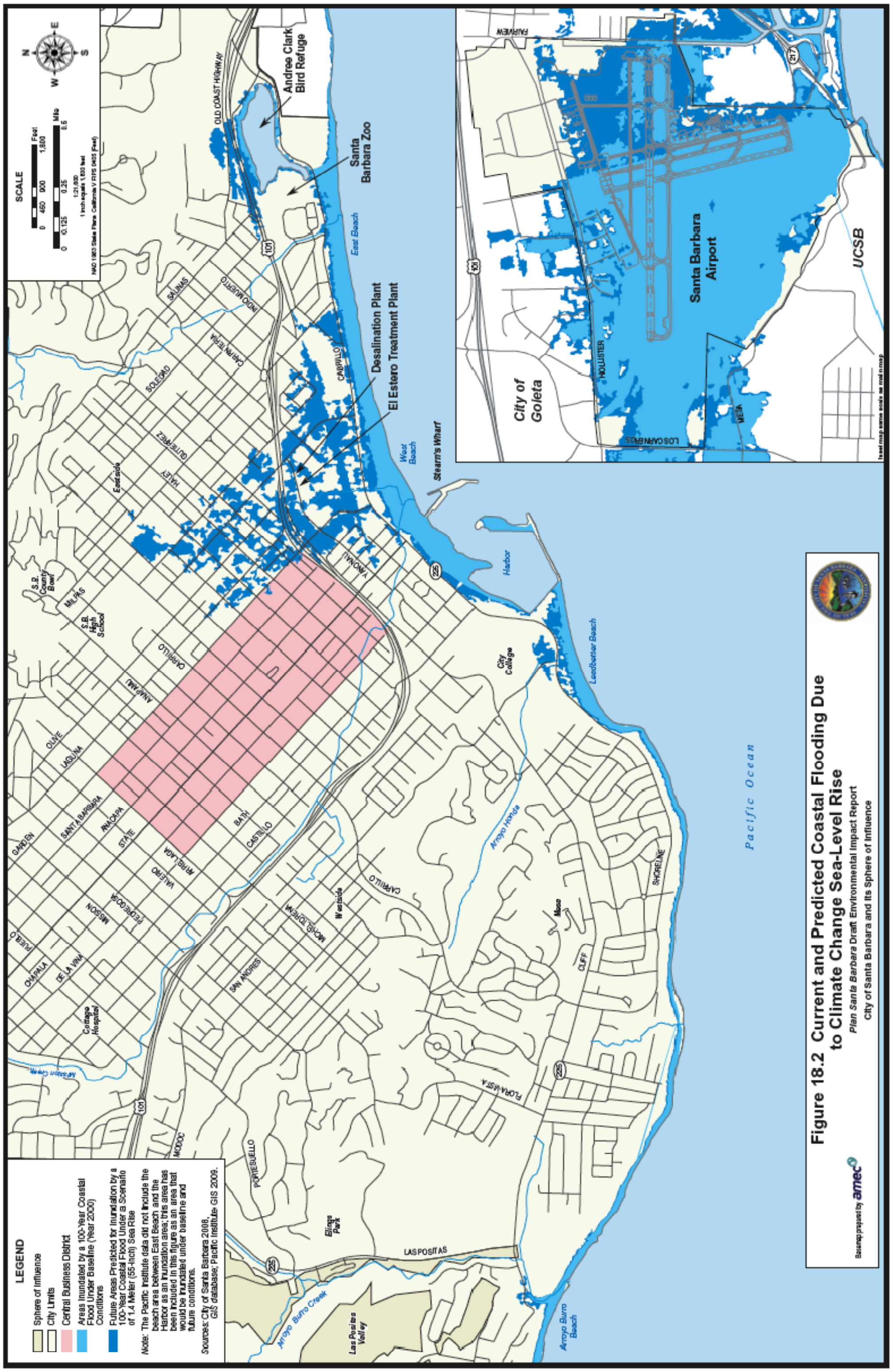

**Figure 2.20: Projected Future Coastal Flood Inundation Map for 100-year Coastal Flooding under Present and 2100 Conditions with 55 Inches of Sea-level Rise**

Source: Plan Santa Barbara EIR

Cabrillo Boulevard is displayed as being overtopped by water. Water also is projected to flood the areas along much of the shoreline and to reach inland as far as Santa Barbara High School on the Eastside. Much of the area that is between the present shoreline and the freeway would be flooded. Inland from the freeway, much of the area between Garden and Quarantina Streets and as far as Carrillo Street is identified as being subject to flooding under the 100-year coastal storm plus 55-inch sea-level rise scenario. However, the lack of precise elevation control through these areas places considerable doubt upon the reliability of this map.

**If the City's own benchmark system can provide relatively accurate and precise elevation control, it is recommended that revised inundation maps be prepared in order to produce a reliable basis for risk analysis and future decision-making. If precise elevation control is unavailable, it is recommended that such data (LiDAR, for example) be collected (perhaps in concert with the elevation control that is needed for defining future flooding and inundation risks at the Santa Barbara Airport).**

In addition, rising sea levels and a high water table could begin to interfere with treated wastewater discharge and/or potentially increase flood hazards at treatment plants in low-lying areas (CCCC 2009). The City's El Estero Wastewater Treatment Plant is located within 0.25 miles of East Beach, at a ground elevation of about 12 to 14 feet above historic mean sea level. This treatment plant currently discharges treated wastewater approximately 1.5 miles offshore in 70 feet of water. While it does not appear likely that the plant could be subject to flooding with modest rises in sea level, projections show that the El Estero facility would be increasingly vulnerable over time to a 100-year flood event with a 4.6-foot rise in sea level. Thus, sea-level rise may necessitate the modification of plant facilities or operations in the coming decades.

In order to analyze accurate and precise topographic data for the Santa Barbara shoreline and improve upon the reliability of the Plan Santa Barbara EIR flood map, pre-El Niño LiDAR data from October 1997 was downloaded from NOAA and processed in ArcGIS for this assessment. The resulting images, which show contour lines for the present high water mark and the extent of 100-year flooding for projected 2050 and 2100 sea levels, were brought into Google Earth in order to produce maps with easily identifiable geographic features (Figures 2.21 and 2.22). The major limitation to the available LiDAR data is that it is focused chiefly upon the shoreline, such that the inland extent of the coverage is limited. For instance, there is no coverage for the Santa Barbara Airport.

In Figure 2.21, LiDAR data shows that 100-year flooding for the projected 2100 sea level covers all of West Beach, reaches parts of Shoreline Drive, and covers the southernmost portion of the parking lot at La Playa Field, as well as most of the parking lot and areas around the structures that are just west of the Harbor and the area just north of the Harbor. (However, the extent of the LiDAR data does not include most of West Cabrillo

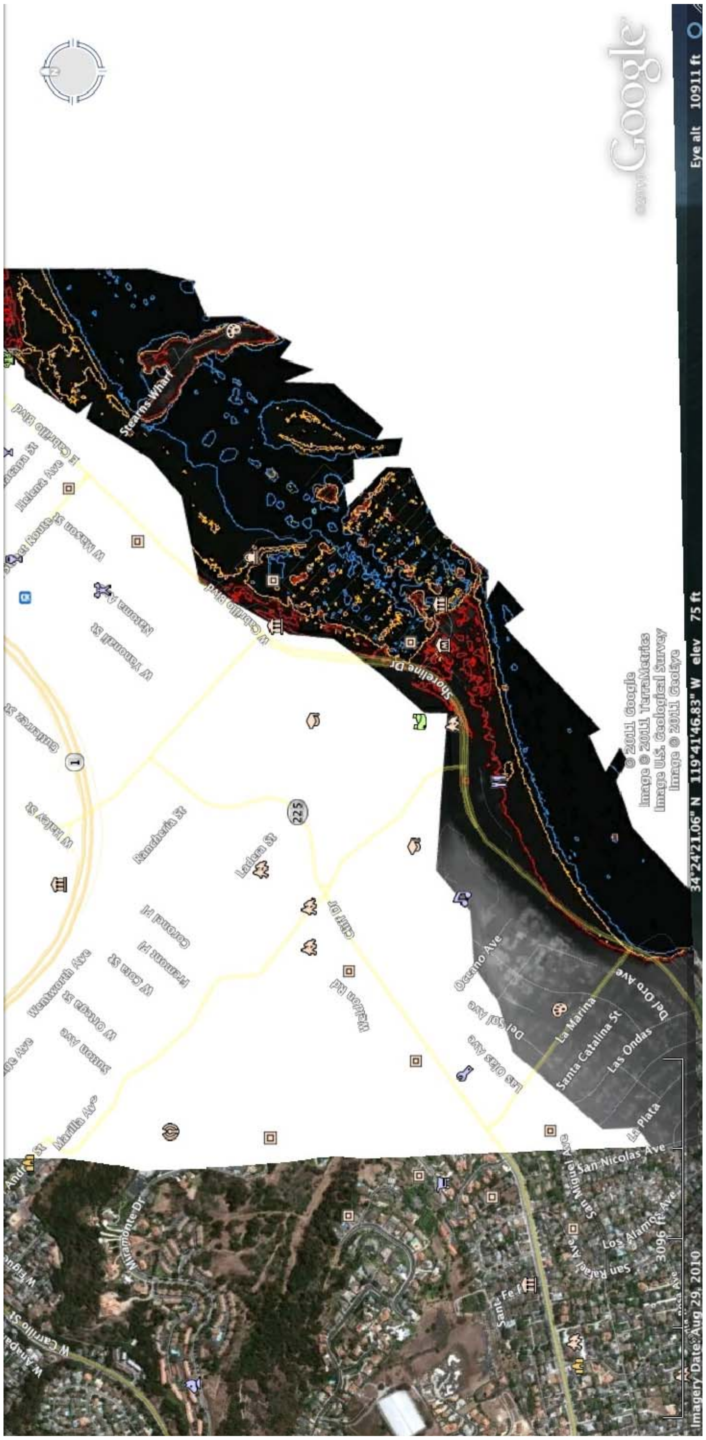

Figure 2.21: Projected Future Coastal Flood Inundation Map for the Santa Barbara Harbor Using October 1997 LiDAR Data and Google Earth. Blue lines show the present high water line at 1.35 meters; gold lines show 3 feet of flooding plus 17 inches of sea-level rise for a total of 2.70 meters for the year 2050; red lines show 3 feet of flooding plus 55 inches of sea-level rise for a total of 3.66 meters for the year 2100. Black and gray areas indicate extent of LiDAR coverage.

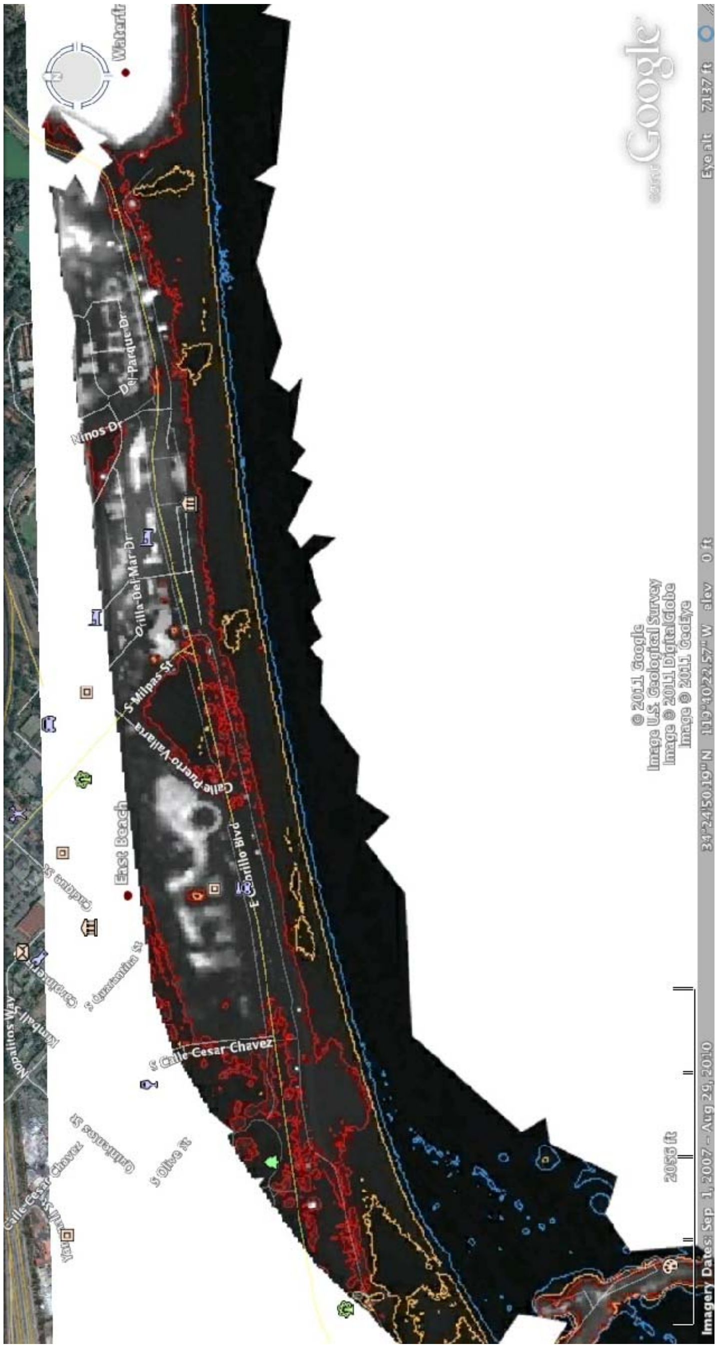

**Figure 2.22: Projected Future Coastal Flood Inundation Map for East Beach Using October 1997 LiDAR Data and Google Earth. Blue lines show the present high water line at 1.35 meters; gold lines show 3 feet of flooding plus 17 inches of sea-level rise for a total of 2.70 meters for the year 2050; red lines show 3 feet of flooding plus 55 inches of sea-level rise for a total of 3.66 meters for the year 2100. Black and gray areas indicate extent of LiDAR coverage.**

Boulevard.) In contrast, the map from the *Plan Santa Barbara EIR* shows that 100-year flooding for the projected 2100 sea level covers La Playa Field and its parking lots (Figure 2.20). Otherwise, the flooded areas on the *Plan Santa Barbara EIR* map are similar to those of Figure 2.20.

In Figure 2.22, LiDAR data shows that 100-year flooding for the projected 2100 sea level covers most of East Beach and extends north of East Cabrillo Boulevard in some locations, covering portions of Chase Palm Park, wrapping around the west side and north sides of the Red Lion Inn property, and covering the entirety of Cabrillo Park. This is similar to what is shown on the *Plan Santa Barbara EIR* map, although the inland extent of flooding is far greater on the *Plan Santa Barbara EIR* map than what is shown by the LiDAR data because the LiDAR coverage is limited in its inland extent (Figures 2.20 and 2.22).

### 2.5.1 The Santa Barbara Airport

The Santa Barbara Municipal Airport, located approximately eight miles west of downtown Santa Barbara, is the largest commercial service airport on the California coast between San Jose and Los Angeles. The City has owned and managed the Airport since 1946 and City limits were extended to include the Airport in 1960. It provides a variety of aviation services, and it is also a major economic benefit to the south coast.

The property consists of approximately 950 acres, with 400 acres for aviation uses, 100 acres for commercial/industrial uses, and 450 acres of Goleta Slough Ecological Reserve.

The Goleta Slough is a 400-acre saltwater marsh and the largest environmentally sensitive habitat in the City's Coastal Zone. It is designated as Recreation Open Space in the 2003 *City of Santa Barbara Coastal Plan for the Airport and Goleta Slough* and ordinances limit its use to educational and scientific activities.

The *Airport Industrial Area Specific Plan*, adopted in 1998, covers 225.2 acres of Airport property along the north and south sides of Hollister Avenue. The overall purpose of the *Specific Plan* is to identify appropriate land uses and locations where implementation will assist in the generation of revenue for the Airport's operation, maintenance, and capital improvements.

The *Aviation Facilities Plan*, adopted in 2003, covers the remaining 725 acres of Airport property, including the airfield and the Goleta Slough. Major components of this plan include relocation of the main runway by 800 feet to the west in order to allow for runway safety areas, relocation of the Carneros and Tecolotito Creeks to accommodate the runway's relocation, and expansion of the airline terminal. Creek relocation was completed in 2006, runway relocation was completed in 2008, and the new airline terminal opened in 2011, with work scheduled for completion by Summer 2012. The new terminal building was raised to three feet above the elevation of the old terminal. Besides relocating the two creeks, the project also called for an increase in the width and depth of sediment basins in the creeks just south of Hollister Avenue, as well as the restoration of 40 acres of upland and wetland habitats in the Goleta Slough. This included 10.3 acres of tidal restoration in a previously impounded basin of the Goleta Slough, and it was completed in 2010.

The Airport was originally built on top of artificial fill within and upon the margins of the Goleta Slough (Figures 2.23 and 2.24), and as such, it is located only a few feet above sea level, much like the San Francisco and Oakland International Airports. Because it lies in an area that sees the convergence of five major streams, the Santa Barbara Airport has historically been subject to flooding. In 1969, water completely surrounded the main terminal (Figures 2.25 and 2.26) and in 1995 and 1998, all three runways were flooded, closing the Airport for several days (Figure 2.27). Public buildings and structures are threatened by inundation during heavy rains and runway flooding poses a safety hazard, preventing planes from taking off and landing.

The Current and Predicted Coastal Flooding Map that was prepared for the *Plan Santa Barbara* EIR outlines the area that is likely to be inundated by a 100-year coastal flood under baseline conditions of the year 2000 (Figure 2.20). Under present conditions, most of the area between Los Carneros Road in the west, Hollister in the north, and Fairview in the east, is projected to be flooded during a 100-year event, as it has in the past.

With a rising sea level, the frequency and magnitude of flooding in the Goleta Slough and Airport area can be expected to increase. The Current and Predicted Coastal Flooding Map (*Plan Santa Barbara* EIR) also highlights the area to be affected by a 100-year coastal flood with 55 inches (1.4 meters) of sea-level rise (near the high end of the projections that the State is currently using for the year 2100). Additional areas of inundation extend east across the entire Airport to past Fairview Avenue and to Ward Memorial Boulevard near Goleta Beach County Park (Figure 2.20).

As discussed in the above section, ***Runoff and Flooding***, the *Plan Santa Barbara* EIR includes a Flood Insurance Rate Map (FIRM) that was produced by FEMA for the Airport area. However, the FIRM maps are not normally based on precise elevation control but instead on existing topographic maps and flood models. In an area where elevations vary by very little over large areas, such as the low-relief Airport site, differences of one or two feet can translate into many acres of additional flooding or inundation. While it is clear that periodic flooding is already a significant concern at the Airport, the uncertainty in the precision of the base maps causes significant uncertainty regarding the boundaries of the areas that are projected to be inundated under various future sea-level rise scenarios. **Detailed topographic mapping (accurate to within at least 12 inches) is necessary in order to be certain about the areas of vulnerability to future flooding and inundation. Plans are in the works for an aerial LiDAR survey of the airport area, which is highly recommended for resolving the existing topographic uncertainties and improving assessments of future inundation risks.**

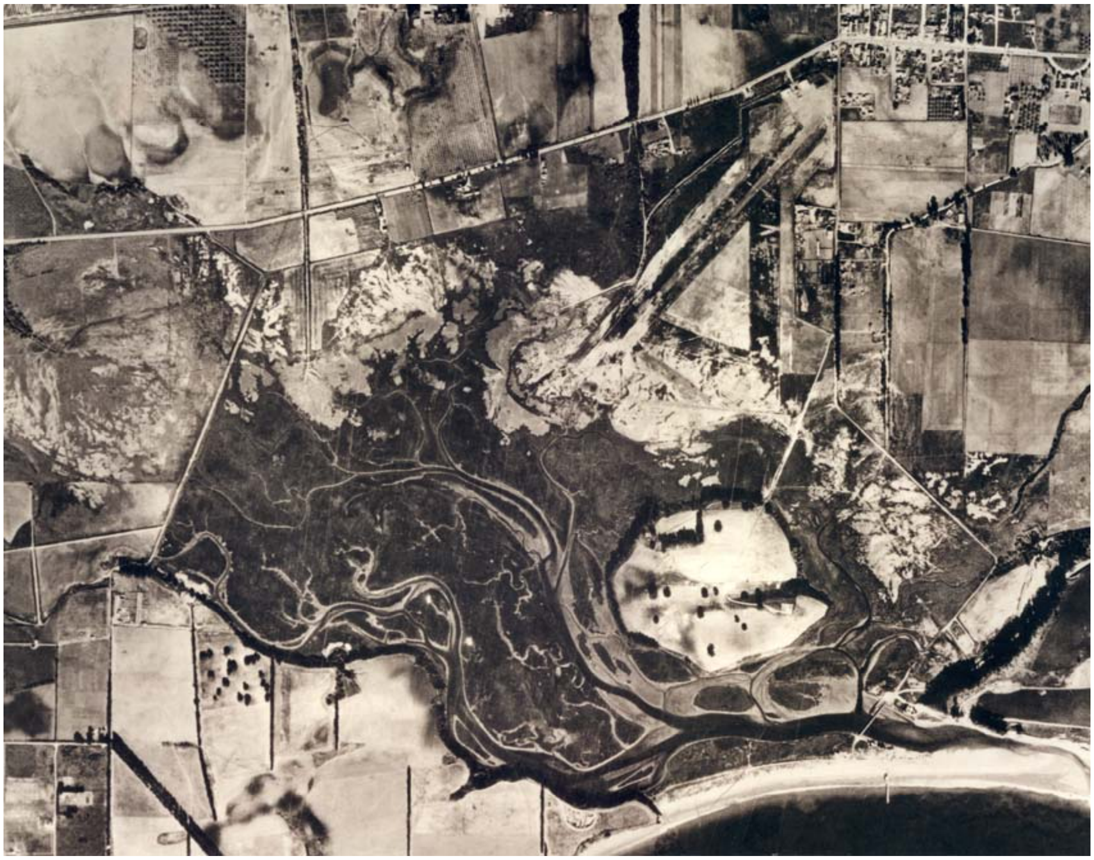

**Figure 2.23: Aerial Photograph of the Santa Barbara Airport Site in 1938. At that time, there was only a small dirt runway that was constructed to fill the slough and create three runways for Marine Corps Air Station Santa Barbara, as part of an Army Corps of Engineers project.**

Source: Santa Barbara Airport

**Figure 2.24: Aerial Photograph of the Santa Barbara Airport in 2010**

Source: Santa Barbara Airport

**Figure 2.25: Flooding of the Santa Barbara Airport Parking Lot in 1969**

Source: Santa Barbara Airport

**Figure 2.26: Flooding of the Airfield in 1969**

Source: Santa Barbara Airport

**Figure 2.27: Santa Barbara Airport Flooding in 1995**

Source: Santa Barbara Airport

## 2.6 Tsunami Hazards

Tsunamis are large ocean waves that are generated by submarine earthquakes, volcanic eruptions, and landslides. These waves travel across the ocean by high speeds (typically by 450–500 miles/hour), and while they go virtually unnoticed in the open ocean, they dramatically increase in height as they reach the shallow waters of a continental shelf. The increased wave height can cause widespread flooding and destruction in low-lying areas along the coast and along low-lying river channels. Devastating tsunamis in the Indian Ocean in 2004 and along the coast of Japan in 2011 provide recent examples of the power and impacts of these waves.

While there is no direct connection between climate change and tsunamis, the effects of tsunamis are likely to be exacerbated by sea-level rise, as rising sea levels will allow tsunami waves to reach greater elevations and travel farther inland than in the past.

Tsunamis that could be generated by large seismic events in distant areas of the Pacific Ocean have the potential to affect the City of Santa Barbara. In addition, local offshore earthquakes could trigger large-scale slope failures in the Santa Barbara Channel (Figure 2.27), resulting in moderate to large local tsunami events (Greene et al. 2006).

According to the records of the California Geological Survey, only three tsunamis have affected the Santa Barbara/Goleta area historically.[2]

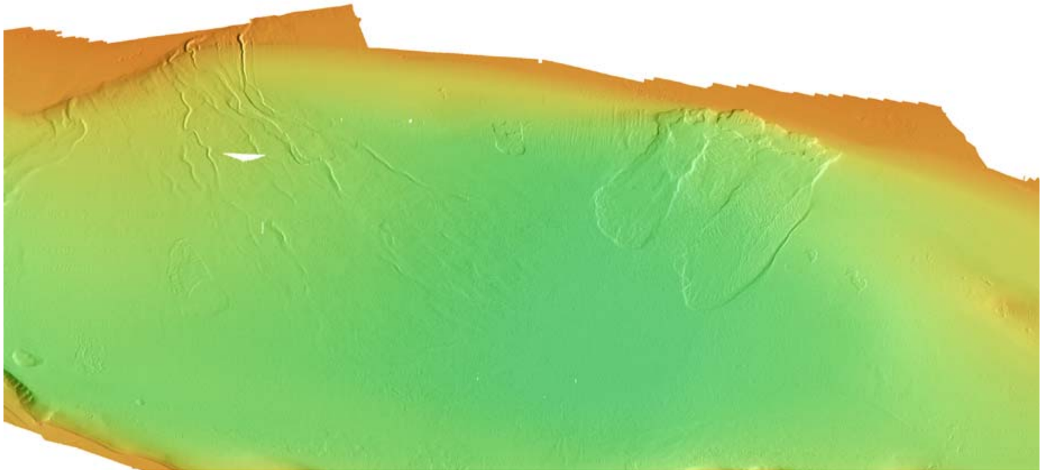

**Figure 2.27: Multibeam Bathymetry Image of Large Seafloor Slumps (on Right Side of Image) along the Santa Barbara Channel, West of Goleta. View is toward the coastline with beige color for the continental shelf and green for the continental slope.**

Source: USGS

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[2] See the California Geological Survey - Tsunamis web page at http://www.consrv.ca.gov/cgs/geologic_hazards/Tsunami/Pages/About_Tsunamis.aspx#historic%20tsunamis%20in%20california.

In Santa Barbara, the earliest documented tsunami occurred in 1812, as a result of several large offshore earthquakes. Many differing and often conflicting historic accounts of the earthquake and associated tsunami(s) exist.[3] A summary by the California Geological Survey reports that the tsunami reached heights of six feet in Santa Barbara, although one questionable account states that the waves reached the very unlikely heights of 30–35 feet at Regugio Canyon, in the west.

In 1877, an especially large earthquake in Chile generated a tsunami that also reached a height of about six feet at Gaviota, although no damage was reported in Santa Barbara. In 1896, an earthquake in southern California generated the most recently recorded sizable tsunami, which reached Santa Barbara with eight-foot waves.

Many large earthquakes have occurred around the Pacific Rim over the past century, and yet there has been no significant inundation or damage recorded within the City of Santa Barbara. Seven of the eight largest global earthquakes since 1900, ranging in magnitude from 8.7 to 9.5 (Table 2.1) have occurred around the Pacific Basin and produced tsunamis elsewhere, but Santa Barbara has been unaffected. Based upon the three reported tsunamis of moderate height (estimated to reach up to six feet in elevation) in the past 200 years, tsunamis appear to be very low-frequency events in the Santa Barbara area, with a low risk of damage.

**Table 2.1: Largest Global Earthquakes from 1900 to 2011**

| RANKING | LOCATION | YEAR | MAGNITUDE |
|---|---|---|---|
| 1 | Chile | 1960 | 9.5 |
| 2 | Alaska | 1964 | 9.2 |
| 3 | Sumatra | 2004 | 9.1 |
| 4 | Japan | 2011 | 9.0 |
| 5 | Kamchatka | 1952 | 9.0 |
| 6 | Chile | 2010 | 8.8 |
| 7 | Ecuador | 1906 | 8.8 |
| 8 | Alaska | 1965 | 8.7 |

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[3] See The Santa Barbara, California, Earthquakes and Tsunami(s) of December 1812. http://www.drgeorgepc.com/Tsunami1812SantaBarbara.html.

The tsunami from the very large March 11, 2011, Japan earthquake reached the Santa Barbara shoreline and elevated sea levels by about 1.5 feet. Local news reported that waves turned the harbor into a tidal pool, sweeping away a barge that was used for the City's commercial fishing operation and nearly destroying a 200-ton crane barge that became unmoored in the tumult. "The whole harbor entrance was kind of chaotic for about five hours," said Santa Barbara Patrol Officer Ryan Kelly. He said several boats were damaged when they collided with barges or other vessels.

# Section 3: Assessing Risks from Sea-Level Rise and Associated Coastal Hazards to the City of Santa Barbara

## 3.1 Introduction

This section assesses the risks posed by each of the coastal hazards that are discussed in the previous section about vulnerability assessment and how these risks may change in the future. A risk assessment includes both (1) assessing the ***probability*** or ***likelihood*** of an event occurring in the future, as well as (2) assessing the ***magnitude*** or ***impact*** of the consequences if the event were to occur.

The future risks from hazards that are associated with sea-level rise are evaluated here for both the *short to intermediate timeframe* (2012–2050) and the *intermediate to long-term timeframe* (2050–2100). We have chosen to use three different levels of ***Magnitude of Impact:*** *Low, Moderate,* and *High*; and four different levels of ***Probability or Likelihood of Occurrence:*** *Low, Moderate, High,* and *Very High*. The terms, "Low, Moderate, High, and Very High," although based upon the sea-level rise scenarios that are suggested for use by the State, are qualitative in this paper, to a degree.

Based upon the trends of the past century and various climate models, the risks from each of these processes or events will almost certainly increase in the future (Figure 1.6 and Table 1.2). Predicting the outcome of future events that are related to sea-level rise (e.g., the inundation of low-lying coastal areas) introduces a level of uncertainty because of the lack of confidence in predicting future levels of greenhouse gas emissions and how these will influence global climate and, consequently, sea level. Because of the short and discontinuous record of sea-level rise from the Santa Barbara tide gauge, there is also some uncertainty about how the coastline is behaving in this area (e.g., long-term changes in beach widths [Orme et al. 2011; Revell and Griggs 2006]; as well as tectonic activity and associated coastal uplift).

Despite this unpredictability, it is still possible to use reasonable judgment about the relative level of risk that each sea-level rise-related process poses to the City of Santa Barbara by using a range of projections for the future. Because the exact extent of future sea-level rise is uncertain, this risk assessment will be scenario-based, using a range of projections for the hazards that are associated with sea-level rise, according to the *medium-high* and *high* future projections that have been adopted by California's state agencies (Table 1.2).

After determining which phenomena and associated impacts are likely to cause the greatest losses, the risk assessment will focus on identifying those areas and facilities, structures, and infrastructure that are most vulnerable to future sea-level rise.

The final step in assessing risk involves evaluating the City's ***adaptive capacity***, since its vulnerability to sea-level rise depends not only upon physical stressors to the local shoreline but also on the ability (e.g., physical and financial) of affected areas to adapt to those changes (e.g., by moving or strengthening facilities). ***Adaptive Capacity*** is rated as Low, Moderate, or High.

## 3.2 Assumptions

For purposes of this risk assessment, we assume that sea level by 2050 will be 14 inches higher than it is today, which is the average (or midpoint) of the State's range of projections (10–17 inches; Table 1.2). Similarly, by 2100, we use 47 inches (the total range in models is 31–69 inches; Table 1.2).

We believe that the highest risks to the City of Santa Barbara in the near-term (from 2012 to 2050) will come from the same types of events that have affected and damaged the shoreline in the past: large El Niño events that generate large waves during high tides and elevated sea levels. Past events have led to cliff failure, beach erosion, and wave damage to shoreline structures and infrastructure. As sea level reaches 18 or so inches above present levels (in the intermediate to long-term), the combined effects of large storms and elevated sea levels are expected to cause greater damage and more widespread flooding, inundation, and beach loss than they have in recent history. The individual Levels of Impact (or Magnitudes and Probabilities of Occurrence) from these hazards for both the short and intermediate timeframe and the intermediate to long-term timeframe are summarized in Tables 3.2 and 3.3.

## 3.3 Increase in Rates of Cliff Erosion

The Mesa area is fronted by actively eroding cliffs, which retreat annually by average rates of 6 to 12 inches. The changing position of the cliff edge is documented in a series of historical aerial photographs, with at least 50 to 75 years between the oldest and the most recent photograph. Average rates of cliff retreat are based upon a comparison of these images. It is important to note that cliff erosion is typically an episodic process, rather than a continuous one. Large cliff failures tend to occur as a result of prolonged rainfall or severe storm events, and failure is often followed by years of stability or little retreat.

Cliff failure is also common below the Clarke Estate and the cemetery on the east end of the City's coastline. The most significant future hazards are in the Mesa area because of its extensive cliff-top development. Two homes were lost in this area during the winter of 1978 due to a large slump that was activated during prolonged rainfall. Another small slide took out part of Shoreline Park in 2008 (Figure 2.6). There are about 98 cliff-front houses along the Mesa and nearly half of these (42) are within 100 feet of the cliff edge, while eight of them are within 50 feet of the cliff edge (Table 3.1). Much of Shoreline Park's walkways and bathrooms, and portions of both parking lots, are within 100 feet of the present cliff edge.

While wave attack is an important driver of most seacliff retreat, there are locations, such as the Mesa, where terrestrial processes are primarily responsible for producing landslides and slope failures. However, once material from the cliffs is delivered to the beach, wave activity is responsible for breaking it down and transporting the fine-grained material alongshore. A continued rise in sea level will cause waves to attack the base of the cliff with an increased frequency, which will increase erosion. In addition, offshore wave data suggests that there is an overall increase in wave heights, although it is still unclear whether this will be a long-term trend or if it is a phenomenon that is related to the PDO off of Central California. Nevertheless, a conservative prediction is that the rate of cliff erosion will increase in the future and the rate of increase will be related to the amount of sea-level rise and the increase in wave energy.

**Table 3.1 Numbers of Cliff-top Homes on the Mesa and Their Distances from Cliff Edge**

| Distance to cliff edge (feet) | 0-50 | 50-75 | 75-100 | 100-125 | 125-150 | 150-200 | >200 |
|---|---|---|---|---|---|---|---|
| Number of homes | 8 | 17 | 19 | 13 | 7 | 7 | 7 |

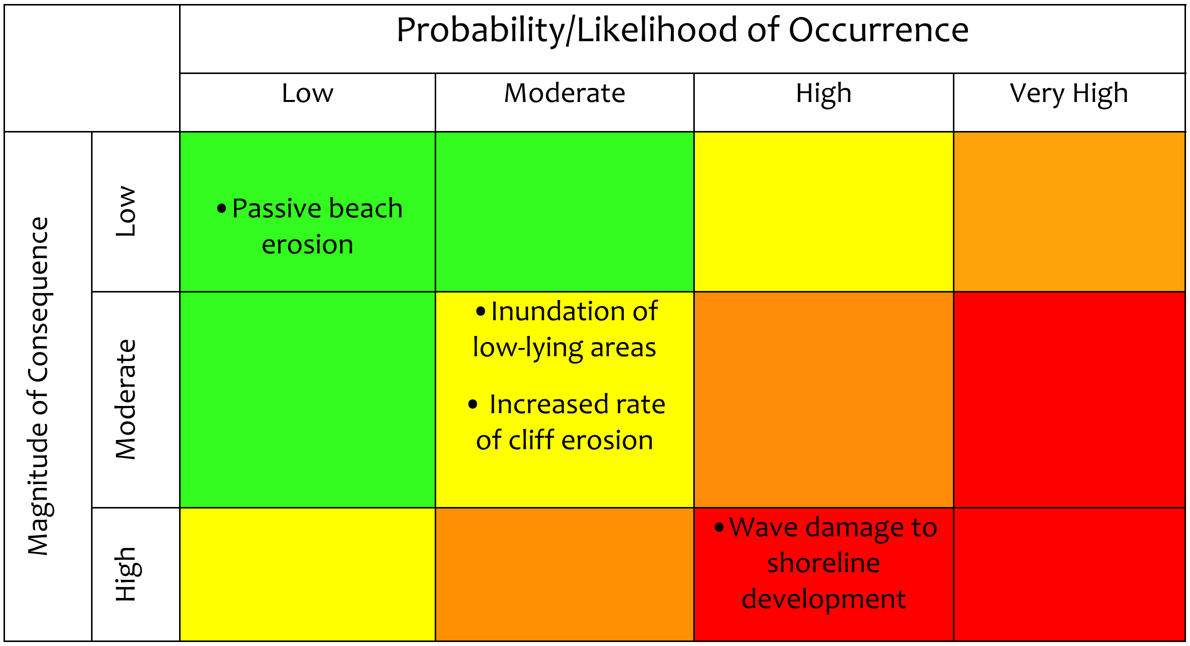
***Probability of Occurrence:*** Over the short to intermediate term (2012–2050), the probability of significantly increased cliff erosion rates is considered to be Moderate (Table 3.2). However, the probability is likely to increase substantially to High or Very High over the intermediate to long term (2050–2100) under sea-level rise values for the year 2100 (47 inches, as adopted by the State) (Table 3.3).

***Magnitude of Consequence:*** If cliff erosion rates on the Mesa remain close to their historical values or increase by a factor of two (to 12–24 inches/year), the cliff edge will likely retreat by about 40 to 80 feet by the year 2050. Such retreat would directly threaten 30 or more homes, as well as a number of secondary structures. This is likely to lead to Moderate consequences (Table 3.2).

If erosion rates double, Santa Barbara can expect to see 80 to 160 feet of erosion from the present cliff edge by the year 2100. This magnitude of retreat would threaten or lead to the relocation of about 67 cliff-top homes. If erosion rates are higher than that in the future, the number of homes that will be affected or threatened will increase. With nearly all of the oceanfront Mesa area homes affected by 2100, this is deemed to have a High impact in the intermediate- to long-term timeframe (Table 3.3).

The *Plan Santa Barbara EIR* includes a map with projected cliff erosion rates for the year 2100. These rates are based upon a model that was developed by PWA/ESA consultants (PWA 2009), which uses the increased exposure of the base of the cliff to wave action due to future sea-level rise. The Shoreline Park area is projected to retreat by 270 feet, while the Mesa is projected to retreat by 525 feet (Figure 2.10). These projections correspond to average erosion rates over the next 88 years that are 3 to 6 times higher (6 to 12 inches/year) in the Shoreline Park area, and 6 to 12 times higher in the Mesa area than those of historic times. Because these numbers are so high and would affect a lot of development, it is important to use these values with caution and to set up a monitoring program for the purpose of tracking cliff retreat.

**Table 3.2: Short to Intermediate-term Risk Analysis Due to Sea-level Rise and Related Processes. Colors from green to yellow, orange, and red indicate increasing risk level. Risks in orange and red boxes are of the highest priority for adaptation action because they will cause the greatest impacts and occur most frequently.**



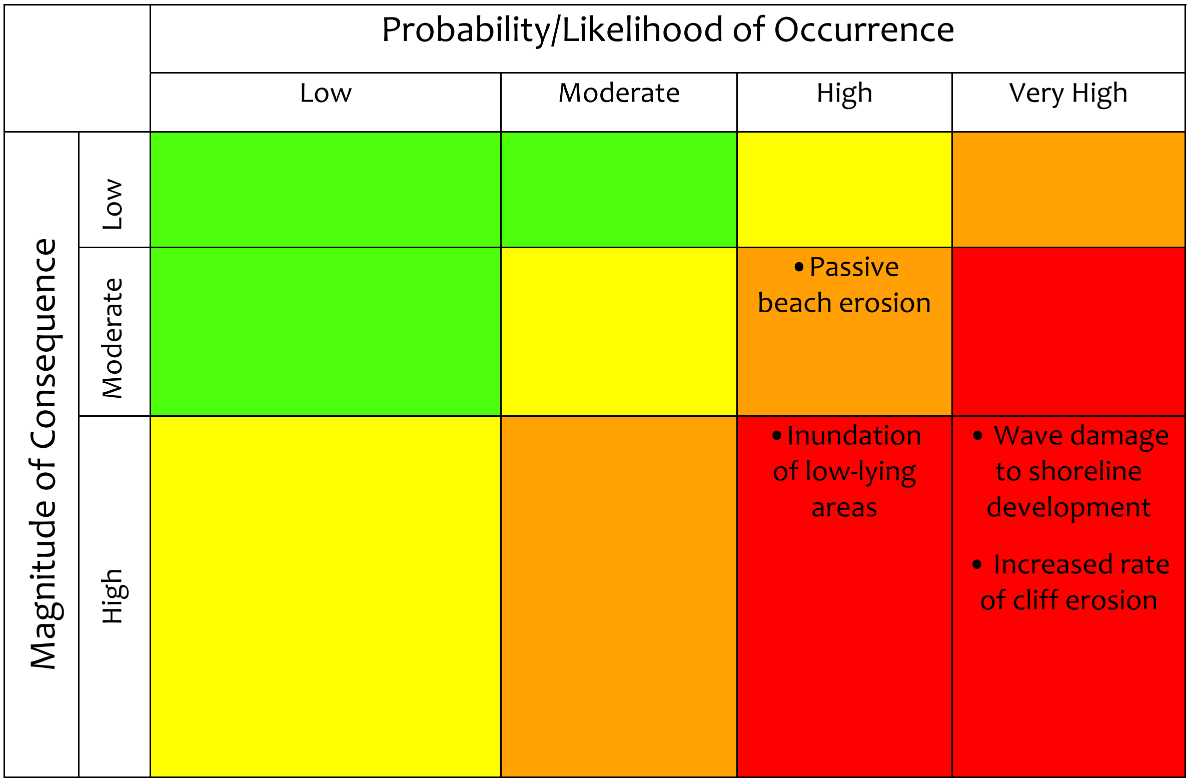
| | | Probability/Likelihood of Occurrence | | | |
|---|---|---|---|---|---|
| | | Low | Moderate | High | Very High |
| Magnitude of Consequence | Low | 🟩 • Passive beach erosion | 🟩 | 🟨 | 🟧 |
| | Moderate | 🟩 | 🟨 • Inundation of low-lying areas<br>• Increased rate of cliff erosion | 🟧 | 🟥 |
| | High | 🟨 | 🟧 | 🟥 • Wave damage to shoreline development | 🟥 |

**Risk = Probability x Consequence**

Short- to Intermediate-Term 2012–2050

Where wave undercutting or marine processes dominate coastal cliff retreat, cliffs tend to be vertical or nearly vertical because undercutting leads to failure of overlying materials (Emery and Kuhn 1982). On the other hand, where terrestrial processes dominate (landslides, slumps, gullying, or terrestrial runoff), coastal cliff and bluffs tend to be more gently sloping than where wave erosion dominates. There are sections of the Mesa where the cliffs are quite steep because the base of the cliff is undercut and failure occurs along bedding planes or dip slopes (Figures 2.7 and 2.8). Wave erosion is probably the dominant erosional process in these areas and increased exposure of the base of the cliff to sea level at high tide, and increasingly large waves could significantly increase rates of cliff retreat.

**Table 3.3: Intermediate to Long-term Risk Analysis Due to Sea-level Rise and Related Processes. Colors from green to yellow, orange, and red indicate increasing risk level. Risks in orange and red boxes are of the highest priority for adaptation action because they will cause the greatest impacts and occur most frequently.**



| | | Probability/Likelihood of Occurrence | | | |
|---|---|---|---|---|---|
| | | Low | Moderate | High | Very High |
| Magnitude of Consequence | Low | 🟩 | 🟩 | 🟨 | 🟧 |
| | Moderate | 🟩 | 🟨 | 🟧 • Passive beach erosion | 🟥 |
| | High | 🟨 | 🟧 | 🟥 • Inundation of low-lying areas | 🟥 • Wave damage to shoreline development<br>• Increased rate of cliff erosion |

**Risk = Probability x Consequence**

Intermediate- to Long-Term 2050–2100

However, there are other areas where slopes are relatively gentle (Figure 2.12) and where it appears that large landslides or slumps, driven primarily by terrestrial processes, are the dominant mode of failure. In these latter cases, a rise in sea level of one or two feet may not cause as great an effect as in those areas where cliff retreat is triggered mainly by wave attack.

As discussed previously, projections for sea-level rise by the year 2050 are in the 10–17 inch range. Such an increase is not expected to cause a large increase in cliff retreat rates along the Santa Barbara City cliffs, but the next 38 years of observation and documentation should provide a good picture of both the changes in sea level and the corresponding changes in cliff erosion rates, such that the City can respond appropriately.

At the eastern end of the City, erosion rates along the Clarke Estate and the cemetery have also historically averaged about six inches to one foot per year. The overall consequences of additional erosion in this location are deemed to be low, although cemetery plots will need to be relocated as the cliff edge encroaches upon them.

## 3.4 Passive Erosion or Inundation of Beaches

***Probability of Occurrence:*** The likelihood of the inundation of City beaches (i.e., passive erosion) will depend upon the future rate(s) of sea-level rise, beach width, and beach elevations (Leadbetter, West, and East beaches). These beaches have all eroded or flooded temporarily in the past, with waves reaching Cabrillo Boulevard under severe weather conditions, such as in the years 1914 and 1983 (Figures 2.16 and 3.1). Inundation, as opposed to short-term flooding, is a virtually permanent condition.

**Figure 3.1: Boat Beached against Seawall during Storms of 1914, Just West of Stearns Wharf**

Over short to intermediate timeframes (i.e., 2012 to 2050), there is a Low probability of the permanent loss of City beaches (by passive erosion) under the 14-inch sea-level rise scenario (Table 3.2). A short-term El Niño event will cause a greater likelihood of beach flooding than will gradual sea-level rise, but again, the former type is a short-term phenomenon, lasting only a few days or weeks.

Over the intermediate to long term (i.e., 2050 to 2100), the probability of the passive erosion of beaches could increase substantially, depending on the elevation of the beach, the heights of back beach barriers, and how high sea level rises. As discussed previously, sea-level rise will gradually move the shorelines of natural, long sandy beaches (such as East Beach) landward, and such beaches will gradually increase in elevation as summer waves move sand high up onto their back beaches. Because East Beach is not particularly wide, this area will likely experience the effects of sea-level rise before Leadbetter and West beaches will. The winter shoreline is expected to begin to encroach upon Cabrillo Boulevard sometime between 2050 and 2100, depending on the rate of future sea-level rise. **It is recommended to establish a set of beach profiles from Leadbetter Beach to the Clarke Estate and a set of winter and summer profiles from Cabrillo Boulevard to the shoreline. These should be surveyed annually in order to keep track of both seasonal and long-term changes. Profile spacing of about 500 feet is reasonable.**

The situation at Leadbetter and West beaches differs from that of East Beach because of the effects of the harbor breakwater, which has widened and stabilized Leadbetter and protected West Beach from direct wave attack. However, even during the summer months, the west end of Leadbetter is only about 75 feet wide; and the east end, toward the breakwater, is only about 50–60 feet wide. Thus, it is likely that sea-level rise will gradually begin to narrow the width of Leadbetter from both of its ends.

The impounding and sheltering effect of the harbor breakwater may serve to hamper beach retreat for a while, but as sea level rises by two, three, or four feet above the present level, it is highly probable that the shoreline will migrate inland and the elevation of the berm will increase. Eventually, under some future combination of sea-level rise and El Niño winter storm conditions, the beach will erode and run-up will reach the back of the beach, overtopping the low seawall along Cabrillo Boulevard (depending upon the seawall's height). Again, the inland extent of storm wave run-up under elevated sea levels will vary from Leadbetter to East Beach and it is dependent upon beach elevations and widths.

***Magnitude of Impact:*** Over the short to intermediate term, the impact on established uses is expected to be Low with only 14 inches of sea-level rise. There may be some beach narrowing, but this will not likely have a large impact. If sea level rises by a lower or higher rate than predicted, the magnitude of the impact will be less or more severe than expected, respectively.

Over the intermediate to long term, with sea-level rise approaching four feet, the impact will be Moderate to High. All City beaches could potentially narrow and gradually disappear from their present locations and be replaced by shallow water or wet sand at low tide. This would clearly have a negative impact on tourism, beach use, and recreation. **Again, a beach profile-monitoring program is recommended for the purpose of tracking future changes.**

## 3.5 Wave Damage to Shoreline Development and Infrastructure

***Probability of Occurrence:*** Shoreline infrastructure and development at the Harbor and along Leadbetter Beach have been damaged in the past by wave attack, particularly when periods of elevated sea levels coincided with large storms and high waves. The 1983 El Niño event is perhaps the best example of this in recent decades. The damage to this area during the first three months of 1983 is well documented in a previous section (see Figures 2.14–2.17). The probability of future wave damage in the short to intermediate term is expected to be High, simply because damage is already happening under conditions of present-day sea level, and the probability of damage will only increase in the future. Over the intermediate to long term, the likelihood of wave damage will be Very High (Tables 3.2 and 3.3).

***Magnitude of Consequence:*** Historically, damage to shoreline structures and infrastructure has been Moderate, but this is expected to increase to High in the near term (by 2050) with ~14 inches of sea-level rise. However, the magnitude of damage will increase to Very High by the year 2100 if sea level rises by four feet above the present level. Park facilities, parking lots, development at the Harbor, the municipal wharf, Shoreline Drive, Cabrillo Boulevard, and associated infrastructure and development that serve visitors along Cabrillo Boulevard will all eventually be at risk from wave attack (Figure 2.15).

## 3.6 Flooding and Inundation of Low-lying Coastal Areas

***Probability of Occurrence:*** As sea level continues to rise, areas that would have formerly only been temporarily flooded or submerged, such as during very high tides or El Niño conditions, such as the Garden Street and Castillo Boulevard underpasses, will gradually begin to be submerged or inundated permanently. Over the short to intermediate term (e.g., ~14 inches of sea-level rise), the probability of inundation along the Santa Barbara shoreline is deemed to be Moderate. Some areas have been flooded in the past during severe storms or El Niño events, and this will become an occurrence of increasing frequency. With a four-foot rise in sea level, the probability of inundation will become Very High.

***Magnitude of Consequence:*** The impact or consequence of inundation is critical to understand due to the extensive area of low-lying land within the lower portion of the City (Figure 2.20), which was discussed in the section about Runoff and Flooding in Section 2. One serious limitation of the mapping in the *Plan Santa Barbara* EIR is that the areas that are highlighted as being subject to a 100-year coastal storm with a 55-inch rise in sea level (which is the midpoint of the high estimate for 2100, in contrast to the 47 inches that the State has adopted; Figure 2.20) include *all* areas that are lower than the critical elevation, whether or not they are directly connected to the shoreline. For instance, Figure 2.20 shows that the freeway lies above the elevation of inundation, but areas that are six blocks inland, as far as Santa Barbara High School, are shown as being flood-prone because of their low elevations, regardless of whether there are barriers at high elevations between these areas and the shoreline. There is also the added risk of stream runoff occurring at times of high tides, such that floodwaters back up along the City's creeks, which becomes an increasing risk as sea level continues to rise. The topographic control for the FEMA map (which was prepared in 1992) is unclear. Large consulting firms prepare most FEMA Flood Insurance Rate Maps by using standardized models and existing topographic information. Because much of the lower portion of the City is of relatively low relief, precise elevation control is critical to evaluating the accuracy of the map that is included in the *Plan Santa Barbara* EIR.

In Figure 2.21, LiDAR data shows that 100-year flooding for the projected 2050 sea level extends inland by about 35 to 70 feet past (north of) the current high water line and crosses into Shoreline Drive in a couple of locations along West Beach. While the flood line banks around the western and northern edges of the Harbor itself, it does not reach the parking lot or structures that are directly west of the Harbor. This changes by 2100, when 100-year flooding is projected to cover all of West Beach and most of East Beach, in addition to covering most of the parking lot and areas around the structures that are to the west of the Harbor, the area just north of the harbor, the southernmost portion of the parking lot at La Playa Field, portions of Chase Palm Park, the entirety of Cabrillo Park, and wrapping around the west and north sides of the Red Lion Inn property (Figures 2.21 and 2.22). Unfortunately, LiDAR data does not extend very far northward into low-elevation areas that are beyond the shoreline, so flooding could be more serious in 2100 than depicted in Figure 2.22.

Until 2050 or so, the magnitude of the impact from flooding and inundation is believed to be Moderate. However, the magnitude of the impact during the intermediate to long term is deemed High, depending upon the precision of elevation mapping.

### 3.6.1 Santa Barbara Airport

***Probability of Occurrence*:** The Santa Barbara Airport has a long history of flooding on both the runways and the terminal area, as described in a previous section (Figures 2.25–2.27). Even without future sea-level rise, flooding will occur the same way as it has in the past, when highly intense and prolonged rainfall increases runoff from the streams that drain into Goleta Slough and combines with high tides. Thus, the probability of flooding is High in the short to intermediate term (to 2050) and vulnerability will increase as sea level rises by up to 14 inches or so.

If sea-level rise approaches or exceeds four feet by 2100, the probability of flooding and permanent inundation of the airport site will become Very High. However, without precise elevation or topographic information, those areas that will be most vulnerable and affected the earliest cannot be known for certain. However, the Plan Santa Barbara Coastal Flooding map provides a useful perspective about the magnitude of the problem of present and future flooding (Figure 2.20).

***Magnitude of Consequence*****:** There are two overlapping areas of concern for short-term flooding and permanent inundation: (1) the Airport terminal and parking areas, and (2) the runways and associated areas for airplanes. The old terminal was subject to flooding (Figures 2.25 and 2.26) and had a floor elevation of about 10 feet above sea level (Andrew Bermond, Santa Barbara Airport, personal communication). The new terminal is approximately 13 feet above sea level (Bermond, personal communication). However, it is not clear how this elevation relates to the FEMA Flood Insurance Rate Map (developed 20 years ago) and the 100-year storm. It is important to compare these elevations in order to see how much freeboard was anticipated with the new terminal and to determine which combination of future sea-level rise and flood conditions will affect the terminal.

While temporary flooding of the runways and Airport parking areas will be a short-term inconvenience as it has been in the past, permanent inundation presents an unacceptable risk. When future sea-level rise reaches the runway during the winter months of regularly high runoff, the magnitude of the consequence will be Very High, as the Airport cannot function under such conditions. Similarly, flooding of the new terminal presents an unacceptable and costly risk, and it will have a Very High magnitude of consequence.

# Section 4: Adaptation to Sea-Level Rise

A recently completed study, *The Impacts of Sea-Level Rise on the California Coast,* which was prepared for the California Ocean Protection Council (OPC) (Pacific Institute 2009), includes a detailed analysis of the current State population, infrastructure, and property that will be at risk from projected sea-level rise if no action is taken to protect the coast. However, the sea-level rise scenario that was developed by the State of California (Figure 1.6 and Table 1.2) by using the medium-to-high greenhouse gas emissions scenarios that come from the Intergovernmental Panel on Climate Change (IPCC) does not reflect the worst-case sea-level rise that could occur. The report also evaluates the cost of building structural measures that would reduce the risks that are associated with sea-level rise. It is important to note that if development continues in the areas at risk, all of these estimates of risks and costs will rise.

No matter what policies are implemented in the future, sea-level rise will inevitably change the character of the California coast. The new OPC report estimates that a 4.5 feet (1.4 meter) rise in sea level will put 480,000 people at risk of a 100-year flood, given today’s population. A wide range of critical infrastructure, including roads and railway lines, airports, sewer and water lines, wastewater treatment facilities, and power plants will be at an increased risk of storm damage and/or inundation from future sea-level rise.

There are uncertainties associated with projections of future sea-level rise. Nevertheless, governments at all levels must continue to make decisions that either implicitly or explicitly make assumptions about what sea level will be for the lifetimes of existing or proposed developments and infrastructure.

## 3.1 Principles for Adaptation and Adaptive Capacity

The following pages discuss coastal adaptation strategies from two major categories—existing development and new development (California Climate Change Center 2009):

> Strategies for existing development (which includes existing infrastructure and other resources that are located in potentially vulnerable areas) include the following:
>
> - Rolling easements or setbacks.
> - Relocation incentives (to get property owners away from high-risk areas), such as tax incentives, transfer of development rights, or government purchase of vulnerable property.
> - Seawalls or other shoreline protection structures for the protection of critical infrastructure.
> - Elevation of facilities.
> - Planned retreat.
> - Rebuilding restrictions for vulnerable structures following sea-level rise-related disasters.
>
> Strategies for new development include the following:
>
> - Mandatory setbacks for the restriction of development in vulnerable areas.
> - Required warning notices for developers and buyers regarding the potential impacts of future sea-level rise.
> - Smart growth and clustered development in low-risk areas.
> - Designing for increased resiliency following sea-level rise-related disasters.
> - Development of expendable or mobile structures in high-risk areas.

## 3.2 Progress on Adaptation Actions at the State Level

The California Resources Agency has recently completed a *2009 California Climate Adaptation Strategy* that includes a section on Ocean and Coastal Resources Adaptation Strategies. It states the following:

> "Given the extent of the threats predicted by current climate models, sea level projections, and the considerable value of California's coastal lands, resources and developments, coastal planning in California must address adaptation to a variety of

> potential significant outcomes of climate change. Preparing California's coastal infrastructure, industries and ecosystems for the impacts of climate changes will be an expensive endeavor. Decision-makers will need to make short- and long-term decisions to address future impacts that will include maintaining existing natural and human developments by protecting, rehabilitating, retrofitting, supplementing, and constructing these systems."
>
> "While the exact future of the coast is uncertain, one thing is clear: we're going to have to change the way we think about managing our natural assets and human development. Existing laws (such as the California Coastal Act) provide State and local governments with tools for addressing the effects of climate change, but also impose some significant limitations. Laws written in and designed for the twentieth century will need to be updated to reflect new ideas about climate change in the twenty-first century." (California Resources Agency 2009)

The 2009 report lists six overall strategies, which provide some State Agency perspective about future adaptation planning for the State's coastline:

1. Establish State policy to avoid future hazards and protect critical habitat.
2. Provide statewide guidance for protecting existing critical ecosystems, existing coastal development, and future investments.
3. State agencies should prepare sea-level rise and climate adaptation plans.
4. Support local planning for addressing sea-level rise impacts.
5. Complete a statewide sea-level rise vulnerability assessment every five years.
6. Support essential data collection and information sharing.

Strategy 4 is specific to the State's interest in local community adaptation planning efforts, and it also includes a set of eight general strategies that are recommended for consideration by local governments in local plan updates:

1. **Setbacks**. Mandatory construction setbacks can be imposed to prohibit construction and significant redevelopment in areas that will likely be affected by sea-level rise within the life of the structure.
2. **Additional Buffer Areas.** Additional buffer areas can be established in some places to protect important cultural and natural resource assets [although natural resources may not be in the same locations in the future].
3. **Clustered Coastal Development.** Coastal development can be concentrated in areas of low vulnerability and may reduce carbon emissions from transportation.
4. **Rebuilding Restriction.** Rebuilding can be restricted when structures are damaged by sea-level rise and coastal storms.
5. **New Development Techniques**. Building codes can be amended to require that coastal development incorporate features that are [of increased resilience] to sea-

level rise (e.g., require that development begin on the second floor).

6. **Relocation Incentives**. Federal, State, and local funding or tax incentives to relocate out of hazard areas.
7. **Rolling Easements**. Policies and funding to facilitate easements to (a) relocate developments further inland, (b) remove development as hazards encroach into developed areas, or (c) facilitate landward movement of coastal ecosystems that are subject to dislocation by sea-level rise and other climate change impacts.
8. **Engineering Solutions**. New engineering approaches will need to be applied to ports, marinas, and other infrastructure that must be located on the shoreline in order to maintain their function as sea level rises.

## 4.3 Protection Structures In California

With the California Coastal Commission's hesitancy to approve any new armoring along the State's coast unless a primary structure or infrastructure is within one or two storm cycles of being undermined or damaged, it has become increasingly difficult to obtain permits for installing additional riprap or seawalls.

City and State policy recognizes cliff and bluff retreat as natural phenomena. The City Local Coastal Program and the State Coastal Act and Coastal Commission actively discourage seawall construction. Policy 6.3 of the City's Local Coastal Program states the following:

> "Seawalls, revetments and bulkheads shall not be permitted unless the City has determined that they are necessary to, and will accomplish the intent of protecting existing principal structures, and that there are no alternatives that are relatively less environmentally or aesthetically damaging, such as relocation of structures, sand augmentation, groins, drainage improvements, etc…" (City of Santa Barbara 1981).

Currently, with the exception of a portion of the Clarke Estate in the east, the vast majority of the City's bluffs remain in a natural unarmored condition.

The City of Santa Barbara currently addresses bluff retreat through the identification of a 75-year sea cliff retreat line that is based upon average annual erosion rates and which is used in the development review process. A recently completed study updated the 75-year average line to adjust projected average annual erosion rates from 8 inches per year to 12 inches per year (AMEC 2010). The 75-year sea cliff retreat line constitutes a screening tool for deciding when to require a site-specific study in order to best determine the location of the 75-year sea cliff retreat line for a particular property. Primary structures are required to be sited to provide for at least a 75-year life, as are remodels and additions. However, the Planning Commission, with the recognition that such structures may not last, may approve secondary and accessory structures. Recent climate change studies indicate that the rate of cliff erosion may accelerate in the future, which needs to be considered.

Public agencies and property owners sometimes armor the coast by constructing seawalls at the bases of sea cliffs in order to prevent or reduce retreat rates and property loss. However, seawalls are known to slow (but *not* halt) bluff retreat, and they may potentially cause secondary impacts that can include reductions in sand supply, decreased beach width, reduced lateral beach access over time, negative visual impacts, and possible negative impacts for adjacent unarmored properties (Griggs 2005).

New cliff-top development must be situated far enough from the edge of a cliff such that exposure to the effects of sea-level rise (as projected by the State of California or by a site-specific geologic investigation that accounts for sea-level rise) is minimized. The design life of a new structure is presumed to be a minimum of 75 years.

Protection for existing cliff-top development and infrastructure shall first focus on techniques that avoid the use of hard coastal protection structures. Preferred measures include: the use of non-intrusive techniques such as drainage control, installation of drought-tolerant landscaping, construction of cantilevered grade beam foundations, removal of threatened outbuildings, etc. Furthermore, the relocation of threatened structures to inland parcels shall be favored over the installation of hard coastal protection structures.

A small number of existing structures that are currently close to the bluff edge could experience damage or destruction over the next 18 years (Table 3.1). Existing City policies may not be adequate for the prevention of damage to or loss of structures.

Future construction, remodeling, and improvements to property in the coastal zone could prolong the trend of increasing property values in areas that are exposed to cliff and bluff retreat hazards. The close proximity of existing and new development to coastal bluffs is expected to expose large numbers of existing homes and other additions along the south coast to severe damage or destruction over the coming decades, which would increase in severity over time.

Actual and potential damage to public and private structures and facilities along City coastal bluffs could lead to an increased demand for coastal armor, particularly if continued residential in-fill and redevelopment projects increase property and structure values in these hazardous areas. Existing City Coastal Plan policies discourage armoring of bluffs and require building setbacks. However, the damage to or the loss of structures over the coming years could increase pressure on the City, County, and other agencies to implement erosion control mechanisms, such as seawalls and riprap revetments.

Some protection structures can substantially reduce bluff erosion and have minimal placement loss and visual impacts (Griggs 2005). However, in places where the erosion of cliffs and bluffs serves as a significant contributor of sand to the littoral system, protection structures can cause negative down-coast impacts by reducing rates of retreat and thus reducing the sand supply from eroding cliffs. However, cliffs in the Santa Barbara littoral cell consist mostly of shale, so the reduction of sand supply through armoring is not believed to be a significant issue (Runyan and Griggs 2003; Patsch and Griggs 2006 a,b). Also, along some parts of the Mesa area, siliceous shale does break down into cobble-sized material, providing some natural cliff protection (Figure 2.12).

The potential damage to coastal property is expected to be substantial in the future. These impacts can be reduced through a combination of managed retreat, natural bluff reinforcement through the planting of native erosion-controlling plant species, and possibly by the selective placement of protection structures, at least over the short to intermediate term.

Measures that could be used for addressing ongoing coastal bluff erosion, sea cliff retreat, and the accelerated erosion of City beaches resulting from sea-level rise include:

1. Adoption of updated bluff retreat standards and building setbacks.

2. Preparation of a Shoreline Management Plan in order to address sand supply and retention, cliff or bluff stabilization, continued interagency coordination, cooperation with affected property owners, and identification of funding. The City of Santa Barbara is a member of BEACON (Beach Erosion Authority for Clean Oceans and Nourishment), which has undertaken a number of regional studies, including their Coastal Regional Sediment Management Plan.[4]

## 4.4 Sea-Level Rise and Coastal Hazards: Adaptation Strategies and Adaptive Capacity

Using the recently completed *Adapting to the Impacts of Climate Change (*National Research Council 2010), the newly released *California Climate Adaptation Strategy* (California Resources Agency 2009), and input from Santa Barbara's City staff, we have evaluated the capacity of the City of Santa Barbara to adapt to each of the hazards associated with future sea-level rise over both the short to intermediate and intermediate to long term (summarized in Table 4.1a, b). A set of possible adaptation actions and strategies was also developed for each of the vulnerabilities and impacts that were recognized and order to reduce the chances of future exposure to harm from sea-level rise. The measures include a broad range of approaches: future planning for hazard avoidance, engineering (including retrofitting, rebuilding, construction and protection), and retreat or relocation.

### 4.4.1 Wave Damage to Shoreline Development and Infrastructure

Increases in sea level and wave energy will both increase the risks of future wave attack upon (and damage to) shoreline development. There are limited adaptive measures for the City's low-lying shoreline areas: beach nourishment, armor, or retreat.

Beach nourishment is discussed in a following section under ***Passive Erosion and***

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[4] See the plan at http://www.beacon.ca.gov/projects/016-CRSMP.htm.

***Inundation of Beaches.*** In essence, Leadbetter Beach has already been widened by hundreds of feet as a result of the breakwater construction in the late 1920s. Nonetheless, significant damage still occurred during the 1983 El Niño winter. West and East Beaches are now nourished by the discharge of sand dredged from the harbor entrance. Because of a rising sea level, as well as the issues that are discussed previously, additional sand will probably not solve the future challenges that are posed by a significant increase in sea level by 2050 and beyond.

While a seawall can help to buffer or protect oceanfront development from wave attack over the short to intermediate term (until 2050), this may require significant investment in the Leadbetter, Harbor, West, and East Beach areas. Over the long term (from 2050–2100), if three to four feet of sea-level rise were to occur and the City beaches were greatly reduced in width or eliminated as a buffer in the winter months, a seawall would need to be of substantial height. By the time that a decision would have to be made about the construction of a seawall along the entire length of the City shoreline, there would presumably be an improved projection for the anticipated additional sea-level rise, as well as any changes in wave conditions. The lifetime of the structure, the protection that would be offered by it, and its potential costs and benefits could then be carefully weighed against a gradual retreat, which may be the only long-term option as sea level continues to rise.

**Table 4.1a: Capacity to Adapt to Sea-level Rise and Associated Impacts over the Short to Intermediate Term (2012–2050)**

| Hazard | Risk | Adaptive Capacity of City of Santa Barbara |
|---|---|---|
| Wave damage to shoreline development and infrastructure | High | Moderate |
| Flooding and inundation of low-lying coastal areas | Moderate | Moderate |
| Increased rates of cliff erosion | Moderate | Low |
| Passive erosion and inundation of beaches | Low | Moderate |

**Table 4.1b: Capacity to Adapt to Sea-level Rise and Associated Impacts over Intermediate to Long Term (2050–2100)**

| Hazard | Risk | Adaptive Capacity of City of Santa Barbara |
|---|---|---|
| Wave damage to shoreline development and infrastructure | High to Very High | Low |
| Flooding and inundation of low-lying coastal areas | High to Very High | Low |
| Increased rates of cliff erosion | Very High | Low |
| Passive erosion and inundation of beaches | High | Low |

Overall, the City's adaptive capacity to future wave attack and damage is deemed to be Moderate over the 2050 timeframe and Low over the 2100 timeframe.

### 4.4.2 Flooding and Inundation of Low-Lying Coastal Areas

The ability for the City to adapt to flooding and then inundation, first along the shoreline and then gradually further inland than ever before, is directly related to the topography that lies immediately inland from the beach and to the amount of sea-level rise. Over the short to intermediate term, the elevated sea levels that are caused by the simultaneous arrival of high El Niño sea levels, high tides, and wave run-up will pose a higher risk to low-lying areas than will global sea-level rise alone. For example, during the 1997–98 El Niño, sea level was typically 6 to nearly 14 inches above the predicted high tide levels at the Santa Barbara tide gauge throughout the month of January. Therefore, the City has the capacity to adapt to 14 inches of sea-level rise by 2050 without major losses, although adaptive capacity will be reduced as sea level rises by more than 14 inches.

With 48 inches of sea-level rise, adaptive capacity will depend upon the distribution of existing barriers to inland inundation that can prevent high tides and increased ocean levels from penetrating into the low elevation downtown areas (as shown in Figure 2.19) or upon the ability to construct barriers for resisting inundation.

The adaptive capacity of the Santa Barbara Airport to future flooding and inundation in the short to intermediate term is believed to be Moderate. The new terminal was apparently sited at an elevation that is three feet above the old terminal, although it is uncertain how this elevation relates specifically to the 14 inches of projected sea-level rise for 2050, when combined with a 100-year flood. It will be important to determine the elevation of a 100-year flood on top of a 14-inch increase in sea level for this area. It also seems possible, although considerably expensive, to raise the runways in order to accommodate the 14-inch sea-level rise and expected flooding conditions for 2050.

However, it appears that neither the terminal nor the runways can easily be adapted to a significantly high rise in sea level by 2100 (four feet are projected). Thus, adaptive capacity is Low by 2100, but there is still time to begin to evaluate all of the options and their costs. As the years progress, we will develop an improved picture of how sea level is changing, such that the appropriate decisions for the future of the Santa Barbara Airport can be made by using relatively accurate projections.

### 4.4.3 Increased Rates of Cliff Erosion

There are two basic approaches for adapting to cliff erosion within the City of Santa Barbara: armor or retreat. Because of the height of the cliffs and the typical failure mechanism, which is usually a large slump or landslide, armoring the toe of the cliffs will probably not be an effective long-term approach. There are scattered boulders and cobbles of Monterey Shale at the base of the cliff along portions of the Mesa (Figure 2.12), but failure typically occurs high on the cliff from weaknesses within the bedrock, rather than primarily by wave attack.

The situation is similar (to that of the Mesa) along the cliffs below the Clarke Estate and the cemetery. Although scattered riprap has been placed there over the years, the riprap has not been effective in halting cliff erosion because failure is occurring high on the cliff, as a result of terrestrial processes (Figure 2.10). Therefore, armor is not an effective mechanism for halting cliff erosion in this location. At both the Clarke Estate and the cemetery, the land is not highly developed, which means that retreat is a relatively easy option.

Retreat, or gradual relocation of the cliff-top homes or infrastructure, is the most effective long-term approach. Therefore, the overall capacity of the City to adapt to the hazards of increased cliff retreat is Low, because there is no buffer zone or physical space to allow for retreat without relocating structures.

### 4.4.4 Passive Erosion or Inundation of Beaches

The ability to adapt to the potential inundation or loss of the City’s beaches is Low to Moderate, depending on the particular beach that is under consideration. Allowing the beach to migrate inland and the shoreline to retreat as sea level gradually rises presents challenges for the City because there is development or infrastructure along the entire back edge of the beaches from west to east, from Leadbetter to East Beach.

Prior to construction of the Santa Barbara breakwater in the late 1920s, the bluff that is now on the inland side of Shoreline Drive was an active sea cliff, and it formed the coastline (Figure 4.1). There was very little beach in front of it, such that high tides and waves regularly reached the base of the cliff, which was actively eroding at the time.

**Figure 4.1: Santa Barbara Offshore Breakwater under Construction in 1928. Note the area between Leadbetter Point and Cabrillo Point and the position of the seacliff prior to sand accumulation upcoast of the breakwater.**

The breakwater began to trap sand as soon as it was connected to Cabrillo Point. In the following years, millions of cubic yards of sand accumulated, moving the shoreline by as much as 600 to 700 feet toward the ocean (Figure 4.2). Everything that is now located seaward of the base of the bluffs, including the Santa Barbara City College stadium and parking lot, Leadbetter beach facilities and parking lots, Shoreline Drive, and all of the buildings and infrastructure that are associated with the harbor (Figure 4.3) was originally part of the seafloor until about 1930.

During the summer months, Leadbetter Beach is about 75 feet wide at its western end, stretching to about 125 to 175 feet in front of the park improvements, and narrowing to 50–60 (or fewer) feet toward the breakwater (widths estimated in August 2010). With significant sea-level rise (at least 24 inches or so), the beach will gradually narrow, with both of its ends eroding before the wide section of beach that fronts the grassy park area erodes. However, this is not expected to be a significant issue until about mid-century, given the projected rates of sea-level rise and the effectiveness of the breakwater in anchoring Leadbetter Beach. **As stated earlier, it is recommended to establish a permanent set of beach transects with ~500-foot alongshore spacing, surveyed in the winter and summer of each year, to document both seasonal and long-term changes as they occur.**

**Figure 4.2: Santa Barbara Breakwater in 1930. The connection of the breakwater to Cabrillo Point serves as a dam and allows the area upcoast of it (to Ledbetter Point) to trap a beach that is hundreds of feet wide.**

Source: Spence Aerial Photo Collection

**Figure 4.3: 2006 Photograph Showing the Development of Area between Cabrillo Point and Ledbetter Point, which was Formerly a Part of the Ocean Floor**

Source: Bruce Perry, California State University Long Beach

Ultimately, it is possible that the park facilities and parking lot could be abandoned and the structures could be removed in order to allow the beach to migrate inland across the former shoreline. The City college parking lot could also be relocated. Shoreline Drive is a critical roadway, though. By the time that the shoreline reaches it, projections for sea-level rise in the decades between 2050 and 2100 will likely have improved, such that the options can be assessed fairly accurately.

From late spring to early fall, West and East beaches vary in width from a maximum of 500 feet adjacent to the harbor (Figure 4.4) to 300 feet at the wharf, thinning to 165 to 225 feet along most of East Beach (Figures 4.5 and 4.6) and widening to 325 feet adjacent to the Clarke Estate. Cabrillo Boulevard marks the back edge of the beach along the entirety of its 1.8 miles. There are also a number of visitor or recreational facilities between the sand and the roadway, including a bike/jogging trail, a skateboard park, parking lots, a beach pavilion, and grassy areas, which are all heavily used year-round. As with Leadbetter Beach, a projected rise in sea level of 14 inches by 2050 will have only a Low to Moderate effect upon West and East beaches because they are relatively wide. However, sea-level rise will likely be increasingly problematic during the period from 2050 to 2100. Because West Beach is partially buffered from direct wave attack by the breakwater, it may sustain itself longer than East Beach will. If these beaches are to be maintained, adaptation may ultimately require removal or relocation of the facilities

**Figure 4.4: West Beach is Very Wide, although it Decreases in Width from West to East**

Source: California Coastal Records Project 2010

Figure 4.5: East Beach, in Front of the Red Lion Inn

Source: California Coastal Records Project 2010

Figure 4.6: East Beach at the Bathing Pavilion

Source: California Coastal Records Project 2010 between the shoreline and Cabrillo Boulevard. Adaptive capacity is deemed Moderate because most of these facilities are movable.

A beach nourishment plan could serve as a short-term solution in an attempt to maintain the beaches in the face of a rising sea level by adding large volumes of sand (that would gradually be transported down coast by littoral drift) to the upper end of Leadbetter Beach on a regular basis. Considerable research has been conducted about the feasibility of beach nourishment along the Santa Barbara coast, sources of appropriate sand, and related issues (see BEACON website).[5] However, there are many issues that would have to be resolved with such a plan.

It is not clear whether there is a sand source that could provide the large volumes that would be necessary for such a project. Also, beach nourishment is very costly and it would be short-lived due to the high littoral drift rates along the Santa Barbara shoreline (~310,000 cubic yards/year). The shoreline has already advanced to a considerable distance seaward by way of breakwater construction, and without a increasing the height or length of the retention structure, there is no reason for additional sand to remain on the City's beaches.

## 4.5 Impediments to Sea-Level Rise Adaptation

Our capacity to respond and to adapt to the new stresses that will result from sea-level rise and associated coastal hazards is limited. In fact, one could argue that our society is not even well adapted to the existing conditions, especially when considering those well-understood natural hazards, such as flooding, that continue to result in disasters for humans. Numerous reports and studies describe the longstanding impediments to the mitigation of natural hazards. These challenges will continue to limit our capacity to adapt to sea-level rise, especially when it involves the intensification of natural hazards (NAS-NRC 2010).

Adaptation requires actions to address chronic, gradual, long-term changes, such as sea-level rise, as well as actions to address the natural hazards that may intensify or increase in frequency in the future as a result of sea-level rise, such as large El Niño storms and flooding (Table 4.2). Addressing gradual changes can be challenging because the eventual extent of such changes is difficult to predict and envision. Plans for the future beyond the next 20 years are often met with skepticism, and the costs for initial investments in adaptation measures may be deemed unaffordable, even when adaptation plans are expected to be cost-effective in the long-term.

For several decades, *adaptation* to sea-level rise has been neglected in the United States, perhaps because it has been perceived as being secondary in importance to the *mitigation*

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[5] BEACON website: http://www.beacon.ca.gov/projects/index.htm.

of climate change (e.g., through the reduction of greenhouse gas emissions) or because it might take attention away from mitigation by implying that the country can simply adapt to future changes. In addition, the subject of climate change and the discussion of options for responding to its effects have become more highly politicized in the United States than in some other parts of the world. Arguments in the media about whether climate change is “real” and how much human influence has played a role in it have confused people about whether action is needed and whether their actions can make any difference at all. Furthermore, there are frequent suggestions in the media that responding to climate change is “too expensive” or that the options for limiting greenhouse gas emissions or for adaptation to climate change will be detrimental to the U.S. economy.

There are those who view climate change only as a rise in temperature of a few degrees, which they consider to be of no concern; those who say that their hands are tied and that they feel powerless, such that they can see no use in trying to change; those who are simply tired of hearing about the problems and are suffering from issue fatigue; and those who have difficulty dealing with probabilities and want perfect information and complete agreement before they are willing to accept the problems and make changes (Moser 2009).

Adaptations to long-term problems involve long-term investments and they also require the consideration of intergenerational equity and other social and economic factors that significantly affect the calculation of costs and benefits.

### Table 4.2: Possible Adaptation Actions for Each Sea-level Rise-related Issue Facing the City of Santa Barbara

| CLIMATE CHANGE PROCESS | IMPACT | POSSIBLE ADAPTATION ACTION |
|---|---|---|
| **Continuing and accelerated sea-level rise** | Inundation of low-lying areas | Design and site all future public works or infrastructure projects to accommodate future sea-level rise based on projected lifespans of projects |
| | | Develop retrofit or retreat plans for existing infrastructure subject to future inundation |
| | | Establish mandatory rolling setbacks (setbacks that move landward over time) for any future developments or significant redevelopment in areas that are likely to be affected by sea-level rise within the anticipated lives of the structures |
| | | Restrict rebuilding when structures are damaged by sea-level rise and coastal storms |
| | | Develop policies and identify funding or tax incentives to relocate away from areas subject to future sea-level rise |
| | | Evaluate costs, impacts and lifespan of a seawall along Cabrillo Boulevard and Shoreline Drive |
| | Passive erosion or inundation of beaches | Allow beach to gradually retreat |
| | | Beach nourishment along with sand retention structures for maintaining beach width over short to intermediate term |
| | | Selectively remove back beach barriers to allow beaches to migrate landward |

Table 4.2: (continued)

| CLIMATE CHANGE PROCESS | IMPACT | POSSIBLE ADAPTATION ACTION |
|---|---|---|
| **Continuing sea-level rise and increased wave energy** | Wave damage to shoreline development and infrastructure | Consider protection in critical areas until no longer feasible due to continued sea-level rise |
| | | Plan for managed retreat for critical and highly vulnerable structures or infrastructure |
| | Increased rates of cliff erosion | Plan for relocation of structures as setback distance from cliff edge decreases and risk of failure increases |
| | | Control drainage and runoff to reduce potential for failure from terrestrial processes |

# Recommended Actions

1. All precautions should be taken to protect the existing NOAA tide gauge at the breakwater from future construction or disturbance such that a long-term record of local sea level change can be established.
2. Establish a cliff edge monitoring program with a set of surveyed transects that can be regularly re-measured, to document and track rates of retreat along all sea cliffs within the City limits.
3. Due to the extent of the area within the low-lying portions of the City that are vulnerable to flooding (according to the Plan Santa Barbara EIR Map), determine the precise elevations throughout the area between the shoreline and the lower portion of the City to improve upon this preliminary assessment. A LiDAR survey is one approach, although existing City benchmarks or survey points may also provide the necessary information.
4. Conduct detailed topographic mapping of the Santa Barbara Airport area, within at least 12 inches of accuracy, to be certain about the areas of vulnerability to future flooding and inundation. Plans are in the works for an aerial LiDAR survey of the airport area, which is highly recommended for resolving the existing topographic uncertainties and improving assessments of future inundation risks.
5. Establish a set of beach profiles from Leadbetter Beach to the Clarke Estate and a set of winter and summer profiles from Cabrillo Boulevard to the shoreline. These should be surveyed annually to track both seasonal and long-term changes. Profile spacing of about 500 feet is reasonable.

# Definitions

**Adaptation:** The adjustment of natural or human systems in response to actual or expected phenomena or their effects such that it minimizes harm or takes advantage of beneficial opportunities.

**Adaptive capacity:** A community's ability to respond to actual or expected phenomena or their effects, including the moderation of potential damages caused by them and coping with the consequences associated with them.

**Assessment:** Processes that involve analyzing and evaluating the state of scientific knowledge and, in interaction with users, developing information applicable to a particular set of issues or decisions.

**Magnitude:** The size or extent of an event.

**Probability:** The odds or potential for an event to occur.

**Resilience:** The ability of an entity or system to absorb some amount of change, including extreme events, and to recover from or adjust easily to the change or other stress.

**Risk:** A combination of the *magnitude* of the potential consequence(s) of climate change impact(s) and the *probability* or *likelihood* that the consequences will occur. The magnitude of the potential consequence(s) is the result of the climate change impact(s) and the system's vulnerability to the changes.

**Vulnerability:** The degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

**Vulnerability assessment:** Risk-based evaluation of the likely sensitivity and response capacity of natural and human systems to the effects of expected phenomena.

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# Glossary

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| BEACON | Beach Erosion Authority for Clean Oceans and Nourishment |
| CDIP | Coastal Data Information Program |
| CO-CAT | Coast and Ocean Climate Action Team |
| EIR | Environmental Impact Report |
| FEMA | Federal Emergency Management Agency |
| FIRM | Flood Insurance Rate Map |
| GIS | Geographical Information Systems |
| IPCC | Intergovernmental Panel on Climate Change |
| LiDAR | Light Detection and Ranging |
| NAS | National Academy of Sciences |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | National Research Council |
| OPC | Ocean Protection Council |
| PDO | Pacific Decadal Oscillation |
| PIER | Public Interest Energy Research |
| Plan SB | Plan Santa Barbara |
| PWA | Philip Williams & Associates |
| RD&D | Research, Development, and Demonstration |