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

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This guidebook is intended to assist managers and planners in California's coastal cities and counties in developing sea level rise adaptation plans for their communities. State agency staff who work with these issues may also find it useful. It begins with an introduction that provides background information about climate change and sea level rise and an explanation of why planners in coastal communities should begin to plan for sea level rise and the associated coastal hazards.

The remaining sections walk users through the processes of performing sea level rise vulnerability assessments and risk analyses for the development of adaptation plans that can be tailored specifically to their individual communities. Readers will also notice examples from or references to two specific case studies in the Guide that we hope will provide some useful perspective. Santa Cruz has completed a Climate Change Vulnerability Assessment that includes sea level rise and related coastal hazards and has now completed a Climate Change Adaptation Plan. We have also worked with the City of Santa Barbara to prepare a Sea Level Rise and Coastal Hazards Vulnerability Assessment to compliment their newly revised General Plan and Environmental Impact Report, which have climate change elements.

Although this Guide is focused on sea level rise and related hazards, it has been informed by several existing but broader climate change adaptation guides and strategies, which are listed in the References at the end of the Guide.

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Chapter 1

INTRODUCTION AND PURPOSE

Sea level rise has been recognized as a significant threat to low-lying coastal areas around the world since the issue of human-influenced global climate change emerged in the 1980s (Barth and Titus, 1984; Milliman et al., 1989; Warrick et al., 1993). A large and growing number of reports and publications demonstrates the large potential impacts of continued sea level rise (Nicholls et al., 2007; Dasgupta et al., 2009). The concentration of people and their assets, including many of the world's major cities along the coasts, makes them hazardous locations as a result of their exposure to coastal storms with large waves, hurricanes, tsunamis and associated flooding (Kron, 2008). Globally, it is now estimated that as many as 20 million people live below normal high tide levels, and over 200 million people are at risk of flooding during temporary storm induced sea level rise (Nichols, 2010). This exposure and the risk levels are increasing as coastal populations continue to grow (McGranahan et al., 2007).

Appropriate responses include climate mitigation (a global response) and/or adaptation (a local response). A combination of these two strategies appears to be the most effective approach to sea level rise, regardless of the uncertainties (Nicholls, 2011). Because there are a number of specific terms used throughout this report, definitions of the most commonly used words are included as an appendix (Appendix A).

During the coming decades, sea level will continue to rise, bringing with it progressive flooding and inundation of low-lying areas as well as increased cliff and bluff erosion. This will be challenging for the State's coastal cities and counties, which are typically densely populated, provide important recreational resources and serve as favored tourist destinations. Much is at stake, and in order to minimize damage and losses, California's coastal communities must make adaptation to sea level rise a priority.

Some city or county planners may be discouraged by the lack of certainty regarding the future rate of sea level rise, but it would be a mistake to allow uncertainty to get in the way of action or preventative measures that are intended to reduce the potential for future damage and losses. Research about sea level rise is ongoing and the new data that are generated by these studies continue to improve our predictions. It seems clear that we are experiencing a long-term upward trajectory or increased rate of global sea level rise. As time passes and more satellite data on sea level are collected and longer tide gauge records become available, the slope of this trend or trajectory will be better constrained than it is today, which will allow us to improve projections for future sea level rise.

The National Research Council is currently conducting a study that was requested by the governors of California, Oregon and Washington in order to provide the most reliable and up-to-date information and guidance on future sea level rise for state, regional and local planning. For most coastal communities, adaptation to sea level rise is likely to be costly, but ignoring sea level rise will surely be a far more expensive choice over the long-term.

Because California is geologically active, its coastline has varied topography. Some coastal communities are subject to slow subsidence, some are relatively stable, while others are being gradually uplifted over time. This complicates the issue of sea level rise, because in the immediate future, it is relative sea level rise at any particular location, combined with short-term increases in sea level (from El Niño events, storm surges, and high tides) and large waves that matter to individual communities, rather than global sea level rise alone. No one adaptation approach or set of approaches will work for every region. That is why it is necessary for individual coastal communities to take on the responsibility of planning for sea level rise, a task that we believe will be more manageable with the use of this Guide.

The procedures and approaches that are outlined in the Guide are informed by work with two of California's coastal communities, Santa Cruz and Santa Barbara. For Santa Cruz, a general Climate Change Vulnerability Study was completed and a Climate Change Adaptation Plan has been written. A Sea Level Rise Vulnerability Assessment was prepared for the city of Santa Barbara during the process of Guide development, so that this Guide could be informed by an actual case study. The approaches to adaptation that are described in the following pages serve as examples of processes that may not suit all communities. Local governments should feel free to adjust the suggested approaches and methods accordingly. We are entering uncharted territory here, and communities can learn from each other about what works and what does not, and coordinate their efforts and responses on a regional basis.

Also, pulling together a Sea Level Rise Preparedness Team (explained in Chapter 2), conducting a vulnerability study, preparing a hazard and risk assessment, selecting appropriate adaptation measures, obtaining funding and implementing adaptation plans may be more complicated than they appear to be here, especially for very large communities.

Realistically speaking, any planning effort in a coastal community in California that involves land use planning is complicated today. While the task may seem daunting, coastal managers and city planners should remember that there is likely already a wealth of information regarding historical coastal hazard vulnerability, and chances are that the types of hazards and risks associated with sea level rise will not be much different from those events which have affected their communities in the past. However, while the types of hazards may not change, their frequencies and magnitudes are changing, which will increase community vulnerability and risk.

If a coastal community is due for a General Plan update anytime soon, it may be easier to incorporate sea level rise adaptation into the Plan than to develop adaptation plans separately later. Although adapting to sea level rise is not yet widespread amongst California's coastal communities, it will be of increasing concern for coastal planners, managers and elected officials everywhere, and hopefully before long, neighboring coastal communities will be able to share information regarding their successes and failures in adapting to sea level rise for mutual benefit.

AWARENESS AND ATTITUDES ABOUT CLIMATE CHANGE AND SEA LEVEL RISE AMONG PLANNERS AND MANAGERS

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

About half the 299 city and county staff responded and 90% of the cities and counties provided input. When asked "What are your attitudes toward preparing for the impacts of global warming", over two-thirds of the respondents indicated they were ready to prepare for the most likely climate-change scenario based on the best available scientific information. The responses of the other third included: they wanted leadership from the top; they already had too much on their plate and couldn't deal with it; or they would rather wait to act until they had better information.

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

The most important type of information desired by coastal managers is the vulnerability assessment for their communities-what will be the most at risk in the future? By identifying what is most vulnerable, they get a clearer idea of what to do to help reduce possible future impacts. Questions like: How far back do I have to tell people they have to build, and how does sea level rise translate into a retreat rate, were examples of desired information.

Planners and managers don't need just information, they need to know how to use that information. They also want to know what other communities have done (Moser, 2007). Local government planning staffs primarily use maps and GIS, and to a far lesser extent, sophisticated analytical or forecasting tools. The clear message from those who responded to the questionnaire was that if we give staff fancy models and projections that they don't know how to integrate into their daily decision-making, they will be less likely to use them effectively. Instead, Moser recommends that the scientific community must translate technical data into practical information in formats that are already in use. With this in mind, we hope the chapters that follow prove to be useful for California's coastal planners, managers and decision makers.

In a follow-up survey conducted in summer 2011, there was a shift in the level of activity on climate adaptation from the 2006 survey. Only two of the responding coastal counties and one city had climate change plans in place at the time of the earlier survey and four more counties and six more cities were developing plans. Of the 2011 responses, representing 14 coastal counties and 45 coastal cities, only 10% had not begun looking at climate change impacts at all, 40% were in the relatively early stage of understanding the potential impacts of climate change and their local vulnerabilities, 41% had entered the more advanced stage of planning for those impacts, and another 9% were implementing one or more identified adaptation options. Coastal communities in California have begun examining and planning for the impacts of climate change.

Chapter 2

CLIMATE CHANGE AND SEA LEVEL RISE

INTRODUCTION

Scientific consensus, based on an overwhelming body of evidence, indicates that global climate is changing, and that it is caused in large part by human activities. Urgent action is needed at all levels of government as well as by industry, communities and individuals to reduce carbon emissions and lessen the extent of climate change, and to begin to adapt to the effects of climate change. Even with such actions, California and the rest of the nation and world will experience increasingly serious and damaging physical, ecological, social and economic effects in the decades ahead.

This chapter is intended to provide some basic information and references on global climate change and sea level rise, both globally and locally. For some readers, this will be interesting and useful background information; for others, it may be unnecessary. But it is included to provide some overall perspective on why we need to begin to plan for climate change along our coastline, what we know and what we are still uncertain about.

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

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 affect and threaten coastal communities and infrastructure through more frequent flooding and gradual inundation, as well as increased cliff, bluff, dune, and shoreline erosion. This will affect transportation facilities; electric utility systems and power plants; wastewater treatment plants, outfalls and storm water systems; ports and harbors; and large wetland areas and coastal development, including homes and businesses.

Worldwide, over 200 million people globally are vulnerable to short-term elevated sea level events or flooding (Nichols, 2010). According to a recent report by the California Climate Change Center

(2009), nearly a 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 at about $47 billion/year, with the great majority of this connected to coastal recreation and tourism as well as shipping and ports. 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 present sea level.

Sea level is expected to rise significantly over the next 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 hundreds of feet due to changes in the volume of seawater and in the configuration or size of the ocean basins. The main additions to increases in ocean water volume come from the expansion of seawater as it warms, and from the breakup and melting of ice caps and glaciers as Earth's climate shifts from cool glacial periods to warm interglacial periods.

There are several well-understood causes for climate change, some short-term and some long-term. Volcanic eruptions can cause short-term cooling by injecting large volumes of particulate matter and gas into the atmosphere. The cooling effects of even large eruptions are relatively short-lived, however, rarely lasting for any longer than a year or two. Changes in solar energy output, such as those associated with sunspots, have relatively short periods also.

The most important contributors to long-term climate fluctuations are those associated with regular and predictable changes in Earth's orbit around the Sun. These include changes in the tilt and wobble of the Earth on its axis and variations in the shape of Earth's orbit around the Sun, which shift over cycles of thousands of years. As a result of these slight orbital variations, the oceans and atmosphere warm when the Earth is relatively close to the Sun and cool when the Earth is farther away. These fluctuations have been the major driving forces behind the Ice Ages of the last several million years. They have caused the growth and decay of ice sheets on and around Antarctica and Greenland, as well as the advances and retreats of the vast continental glaciers. When the Earth is warm, glaciers retreat, ice caps melt and the volume of the oceans increases. Seawater expands when it is warmed, which also raises global sea level. While the primary processes that cause sea level to rise and fall have remained practically constant throughout Earth's history, the rate at which these processes proceed has not.

Our longest actual records of sea level come from coastal tide gauges or water level recorders, some of which extend back 150 years or longer. Tide gauge records from coastlines around the world indicate that global sea level rose about 7 inches during the 20th century (about 1.7 millimeters per year) (Figures 2.1 and 2.2). 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. This can vary from place to place, however, as a result of either the uplift or subsidence of the land.

For the locations where the land is rising, the rate of sea level rise may be outpaced by the rate of coastal uplift. At Crescent City, for example, along the northern California coast, the local NOAA tide gauge records show a drop in sea level of two inches, or 0.65 mm/yr since 1933 when the gauge was first installed (Figure 2.3). The northern California and southern Oregon coasts are both being uplifted due to tectonic activity, which proceeds in those locations today at a rate 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.

Although there are regional differences, long-term tide gauge records have been compiled from the most geologically stable coastlines around the world in order to determine that the global average rate of sea level rise was about 1.7 mm/yr during the 20th century (Figure 2.2).

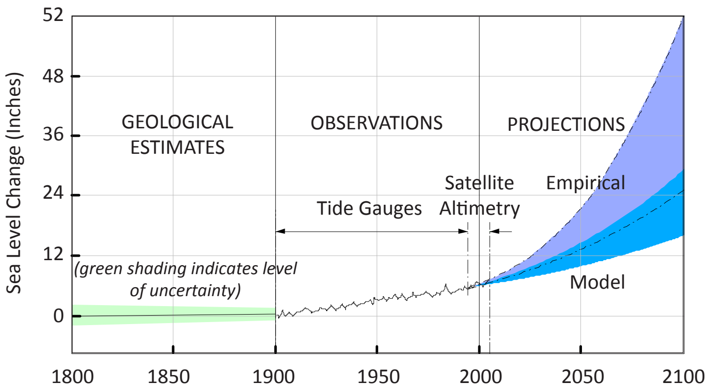


Figure 2.1. Geologic and recent sea level rise histories and predictions (updated from Shum & Kuo).

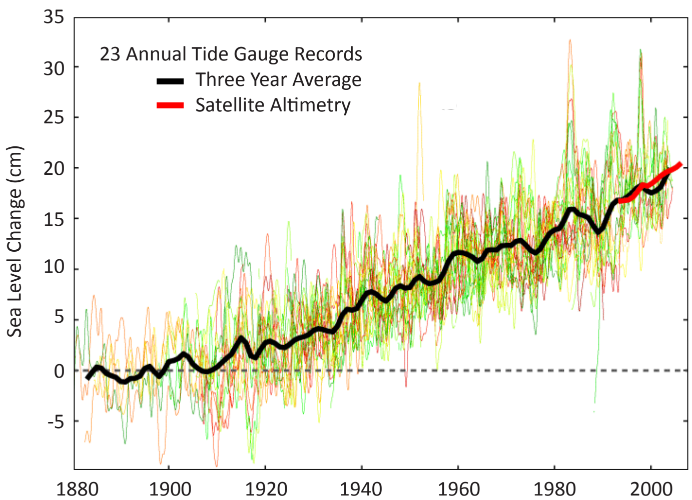


Figure 2.2. Recent sea level rise history from tide gauges and satellite measurements.

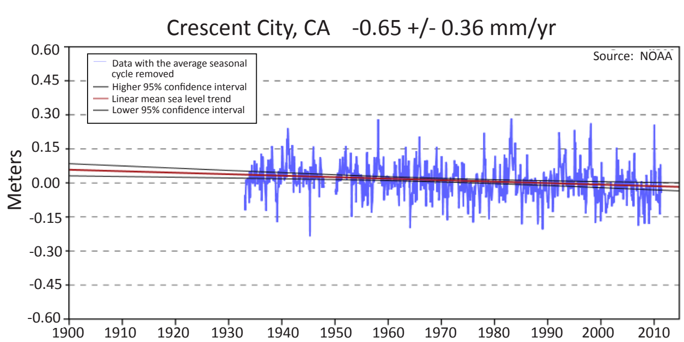


Figure 2.3. Tide Gauge Record for Crescent City, California.

Beginning in 1992, several satellites have been launched with the capability of measuring the level of the ocean from space very accurately. The 18 years of data that have been collected to date are free of the effects of vertical land movements that can affect tide gauge measurements. They indicate that the global rate of sea level rise has increased to a little over three millimeters per year between 1993 and 2010 (Figure 2.4).

Recent research and climate change analysis 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 were previously anticipated.

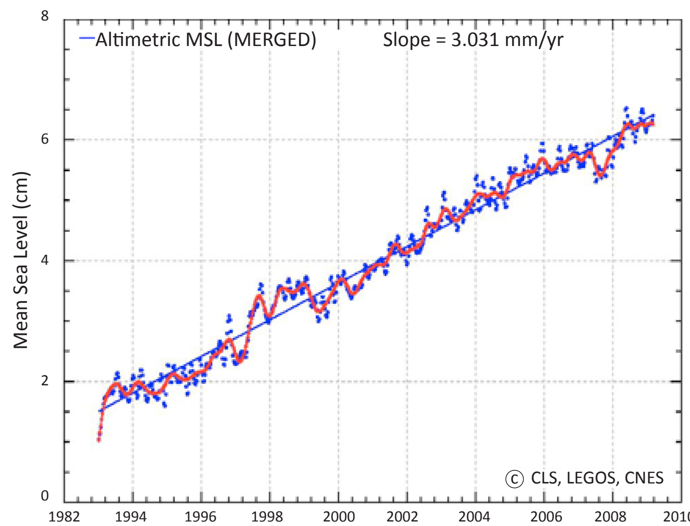


Figure 2.4. Mean global sea level as measured from space from 1992 to 2010 by satellite altimetry. (from the AVISO altimetry product)

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

There are large uncertainties in our future estimates of global sea level rise, however. One major unknown is the future generation of greenhouse gases, which is related to both global politics and societal behavior. Another group of unknowns are those associated with the physical processes themselves: How will large ice sheets respond to a more rapid climate change? What will be the effects of a changing cloud cover? Will the release of methane from the thawing of permafrost have a significant effect on greenhouse gas concentrations and therefore, global temperatures? We don't have answers to these questions yet, but continued observations and research will help us to resolve these uncertainties and enable us to make better furture decisions.

CALIFORNIA SEA LEVEL RISE

Sea level rise has been taking place since the end of the last Ice Age, about 20,000 years ago. Although global sea level rise has been fairly gradual, coastal California has noticeably experienced its effects for at least the past century. According to the 2009 California Climate Adaptation Strategy, sea level has risen by an average of about 7 inches along California's 1100-mile coastline during this period, contributing to progressive shoreline retreat and coastal cliff, bluff and dune erosion.

Continuing sea level rise during the decades ahead will exacerbate the effects of storm surge, large waves and high tides (California Climate Change Center, 2009). Nearly half a million Californians will be at risk from future sea level rise along bay and coastal areas. If California's coastal communities are to avoid or lessen the effects of sea level rise and other associated climate changes, they must begin to adapt now to the anticipated future conditions.

By the year 2100, mean sea level may rise by as much as 40 to 55 inches (1 to 1.4 meters) along the coast of California, although these projections are being modified as observations continue to be made and additional data become available. The California Ocean Protection Council, working with the Coast and Ocean Climate Action Team (CO-CAT), which consists of representatives from 15 different state agencies, have adopted interim sea level rise projections for the decades ahead using the high scenarios in all cases for 2030, 2050, 2070 and 2100 (Table 2.1).

Year		Average of Models	Range of Models
2030		7 in (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)	18-29 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)

Table 2.1. Sea-Level Rise Projections[1] using 2000 as the Baseline adopted by California Ocean Protection Council.

Rates of sea level rise are region-specific because long-term land motion influences sea level at any individual location. In California, sea level has been measured historically at 14 different tide gauge stations between San Diego and Crescent City, although two of these stations were discontinued during the 1990's (Table 2.2). Eight of the stations have at least 50 years of data, and the oldest station at San Francisco has been in operation since 1857 (Table 2.2).

[1] For dates after 2050, Table 2.1 includes three different values for sea level rise - based on low, medium, and high greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

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

Table 2.2. Historic Sea-Level Rise Rates from 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).

Local sea level rise rates at 10 of the 12 stations covering the 800 miles from San Diego to Point Reyes vary surprising 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. A close look at the San Francisco tide gauge at Fort Point, near the Golden Gate Bridge, for example, reveals the clear signature of large El Niño events that have affected the coastline at various points in the past century (Figure 2.5). 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, or 1.77 ft higher than predicted, the highest in over a century of record keeping. Sea levels in Los Angeles that year were also the highest in sixty years of tide gauge history, (7.96 ft, or 1.06 ft above predicted), as they were 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 these extreme tides, the 1997-98 El Niño also was accompanied by sustained periods of elevated sea levels. The following chapters will discuss the importance of these short-term events to coastal flooding and damage in contrast to the more gradual long-term sea level rise.

Historical extreme sea level data from El Niño and other events at California's tide gauges can be downloaded from the NOAA websites:

http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml
and
http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic+Tide+Data

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 2.6). Just 80 miles north at Crescent City, sea level is dropping relative to the coastline by 2.5 inches per century (0.65 millimeters per year) (Figure 2.6). The shoreline at Humboldt Bay is subsiding, whereas Crescent City's coastline is rising.

Because the relative rate of sea level rise differs from one location to another along California's coastline, one number cannot be used everywhere. Each community should utilize the locally appropriate rate and develop adaptation strategies that are suitable for that rate as well as all other community attributes. These would include local topography, development intensity, geology and exposure to other climate related or coastal hazards (e.g. the increasing frequency and height of storm waves; tsunamis, etc.).

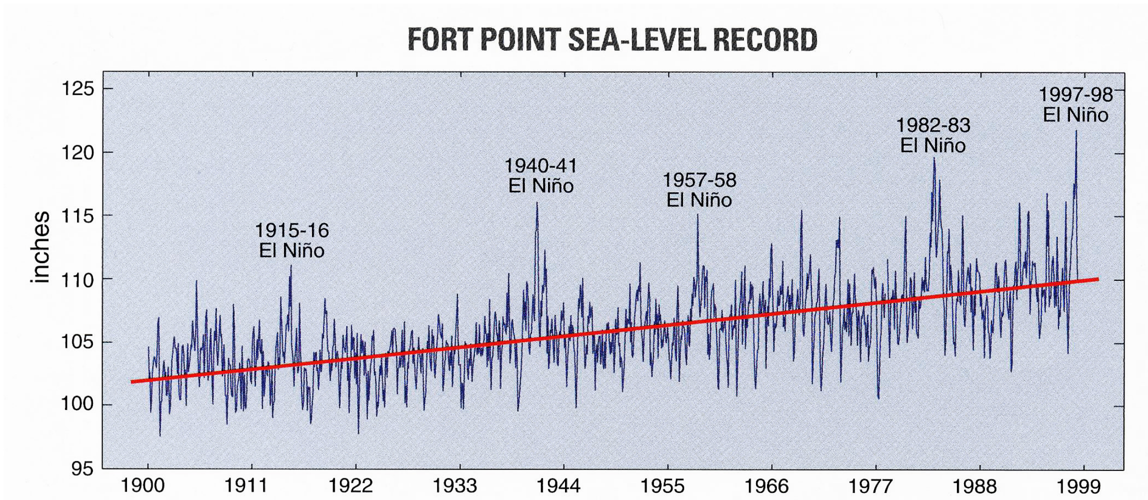


Figure 2.5. Fort Point Sea Level Record.

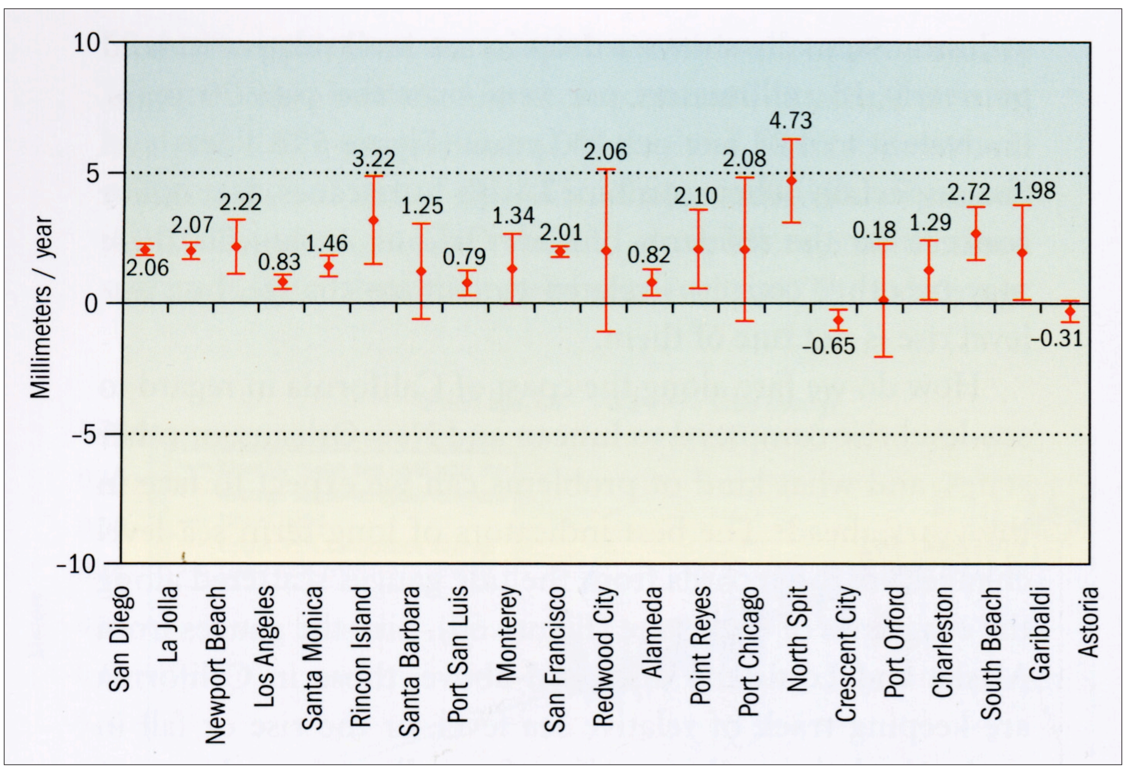


Figure 2.6. Local sea level rise rates along the coast of California and Oregon showing average sea level rise rate from each tide gauge (red dot) and 95% confidence interval range (top and bottom of red bar) (from Griggs, 2010).

Chapter 3

CONDUCTING A SEA LEVEL RISE AND COASTAL HAZARDS VULNERABILITY ASSESSMENT

Adapting to Sea Level Rise: A Guide for California's Coastal Communities is intended to serve as a guide for California's coastal managers and community planners to develop adaptation plans for sea level rise that are suited to their local conditions and communities. We hope that this document will also be accessible to and useful for the different state agencies that must deal with future sea level issues. The Guide includes an outline and explanation of the individual steps that are involved in developing a Sea Level Rise Adaptation Plan for a coastal community, a discussion of the issues that are of concern, and as well as references to resources or tools that can assist a community in developing their individual plan.

Through an understanding of their vulnerability to and risks from sea level rise, individual communities will be able to obtain and use the most accurate and current data that are relevant to their regions in order to conduct vulnerability assessments and risk analyses, and for developing their own adaptation plans.

INTRODUCTION- GETTING STARTED

In order to adapt to future change, coastal communities need to have an understanding of vulnerability and risk, because adaptation to sea level rise is a risk management strategy, somewhat like an insurance policy, against an uncertain future. Risk exposure is covered in Chapter 4 and combines the probability that future events associated with sea level rise are likely to occur (i.e. shoreline flooding, inundation, increased coastal cliff or bluff erosion, etc.) with the magnitude or severity of the consequences of those events taking place.

As mentioned earlier, a list of definitions of key words is included at the end of this guide.

A vulnerability assessment is the first step in the process of developing an informed sea level rise adaptation plan (Figure 3.1). Assessing a community's vulnerability to sea level rise needs to consider three factors: 1] the probable magnitude of sea level rise and its associated impacts; 2] the sensitivity or exposure of the planning area to sea level rise and future storm and wave impacts;

and 3] the ability of the community to adapt or respond to the anticipated impacts.

A vulnerability assessment should include an evaluation of the degree of a community's exposure to various shoreline hazards as well as the magnitude of the impact in the case of a significant event, such as a large El Niño storm or storm surge that elevates sea level significantly. In turn, adaptation is the adjustment of natural or human systems to actual or expected phenomena or their effects, such that it minimizes damage or harm. A coastal community's adaptive capacity is defined by its ability to respond to sea level rise and other coastal hazards. This includes the reduction or moderation of potential damages and coping with their expected or predicted consequences.

Changes are taking place in the ocean that have the potential to affect coastal communities in California. Each one needs to be understood and considered. The specific processes or impacts include:

1. a continuing rise in local sea level with gradual flooding of low-lying areas in the short-term and permanent inundation in the long-term;

2. the combined effects of short-term sea level increases, high tides and large waves that are often associated with El Niño storm events, which can produce short-term flooding and accelerated rates of erosion;

3. increased wave heights and increased or accelerated rates of cliff, bluff or dune retreat.

USING A TEAM APPROACH

One approach for conducting a coastal hazards vulnerability assessment is to form a Sea Level Rise/Coastal Hazard Preparedness Team (abbreviated the Team), which can be a formal or informal group. The quality, value and acceptance of any adaptation plan ultimately depends upon the involvement and buy-in of the directors of the public agencies that stand to be affected by sea level rise and associated impacts. Political leaders and/or elected officials will also need to be on board prior to plan completion and adoption.

Team makeup may vary according to a community's size, resources and vulnerability to sea level rise. The Team could involve or include local government staff from economic development, emergency response agencies, parks and recreation, planning and zoning, transportation, public works including flood control, wastewater treatment, water supply, and port and harbor management, or some combination of these that is appropriate for the individual city or county. Other potential team members may include consultants, scientific advisors, or members of the business community.

Depending on the formality of the group, the composition of the Team might change as it moves through the vulnerability assessment process. It is possible that sea level rise will affect more sectors of a community than the Team initially realizes, so members may be added. On the other hand, some members may not be needed if the assessment reveals less vulnerability in certain sectors than anticipated.

As with any group process, there are tradeoffs. A large group tends to be very inclusive, allowing for the opportunity to engage all sectors or departments, and thus including as many perspectives as possible. However, large committees or teams can be unwieldy, making meeting planning a challenge. They also raise the potential for difficult personal interactions and will produce time demands on a large number of staff from multiple agencies. A small team of core representatives from critical departments or sectors may be more effective than a large group. Small teams should keep all other departments or sectors informed through the regular distribution of progress reports and draft adaptation plans for review, thereby providing avenues for fresh input and insuring that key departments and/or administrators are not left out of the process.

USING A CONSULTANT

Many city and county staff have full schedules, especially with budget and staff cuts associated with the state's economic downturn, often making it difficult for them to find time to dedicate to additional planning efforts and committee meetings (Moser 2007). A more efficient and effective approach for sea level rise planning is to utilize a consultant or consulting firm working with a small group of key city or county agency staff.

A carefully selected consultant or consulting firm should have expertise and experience in the relevant issues (climate change and sea level rise, coastal processes and hazards, for example), a strong track record of working successfully with coastal communities, and the time necessary for completing the entire planning process within a finite period. In this case, the Team may consist of the consultant and several key local government department staff, using other staff members as resources for providing input and information about specific issues, reviewing draft documents and assisting with the editing and preparation of a final plan. Local ownership of the final adaptation plan is important and a good reason for ongoing involvement of the local government staff. It is easier to put a consultant's report on a shelf and forget about it, in contrast to ignoring what a group of city or county staff people worked hard on, come to believe in, and are passionate about.

In any case, no consultant can or should work alone. City or county staff who have worked in a particular agency, department, or community for decades will usually have far more background and historical information, data, and resources than a consultant can obtain or collect in the time available to prepare a plan. Thus, sea level rise adaptation plans should be informed from the outset by the best local knowledge and experience available so that they are accurate and credible.

The City of Santa Cruz obtained a federal grant to prepare a Climate Change Vulnerability Assessment (which included sea level rise). They contracted two University of California faculty (a coastal geologist, the co-author of this guide, and a water policy scientist) as consultants to work with a small group of city Planning Department and Redevelopment Agency staff. Throughout the study, the consultants met with staff from other city departments (water, fire, public works, flood control, emergency response, etc.) to obtain specific information, relevant documents, and staff's perspectives on areas and levels of concern for the assessment. This turned out to be a very effective approach, in part because the faculty consultants were very familiar with the city, had worked with city staff on other issues, so there was little start up time needed. Costs were low, limited by the grant funds obtained, and the consultant team performed and drafted the vulnerability assessment, thereby requiring relatively little staff time. In this case, a Redevelopment Agency staff member used the Vulnerability Assessment as the basis for writing the actual Adaptation Plan.

In the case of Santa Barbara, the authors of this guide (a professor and Ph.D. student) selected the City of Santa Barbara for the preparation of a community sea level rise vulnerability assessment. The authors initially communicated with city planning staff to propose the study, to determine if the city was interested in cooperating on such an effort, and to find out if timing for such an assessment was appropriate. Because the city was just completing a General Plan revision and Environmental Impact Report that included a Climate Change component, timing and the topic seemed ideal. The authors met at the beginning of the study with all of the appropriate city department heads or their assistants, explained the project and intent of the assessment and asked for input, data and information, as well as suggestions from the staff members. Information provided was not extensive, although what was provided was helpful.

The co-authors then used the draft guide as an outline for how to proceed. With occasional communication with city planning department staff and using the information they and other staff provided, as well as the relevant sections of the revised General Plan and EIR, and a general familiarity with the city's coastline and its history of coastal hazards, the authors began to develop a draft sea level rise vulnerability assessment. Because the authors were funded as part of the CEC-PIER program, there was no cost to the city of Santa Barbara for the study.

Information, photographs and maps of historic coastal storm damage, flooding and cliff erosion were solicited and collected. The historical aerial photos available on-line from the California Coast Records Project (*http://www.californiacoastline.org*) proved to be extremely useful for evaluating the entire Santa Barbara coastline. Draft versions were reviewed by City department staff and follow-up conference calls were also useful in preparation of the final vulnerability assessment.

TASKS OF A SEA LEVEL RISE/COASTAL HAZARD PREPAREDNESS TEAM

Regardless of the selected approach, a Sea Level Rise/Coastal Hazard Preparedness Team (the Team) will need to carry out the following tasks as part of the Sea Level Rise Vulnerability Assessment (Figure 3.1). These will each be explained in subsequent sections. Additional steps follow after the local governing body approves the Plan, although these would fall to the local agency that has responsibility for plan implementation:

1. Conduct an assessment to determine which areas are most vulnerable to future flooding, inundation and erosion or damage from sea level rise, a changing wave climate, and related processes.

   Task A. Collect all information on community's historical vulnerability to and damage from coastal hazards.

   i. Collect reports, maps, surveys, photographs, newspaper archives or any other relevant historic information on storm inundation, flood damage, cliff erosion, and beach loss or shoreline retreat.
   ii. Delineate historically flooded, inundated or damaged areas.

   Task B. Obtain historic sea level data using the closest tide gauge or gauges.

   Task C. Obtain the most recent state projections for sea level rise at different future time horizons (e.g. 2030, 2050, and 2100).

   Task D. Collect information on short-term increases in sea level, exposure to El Niño events and changes in wave climate

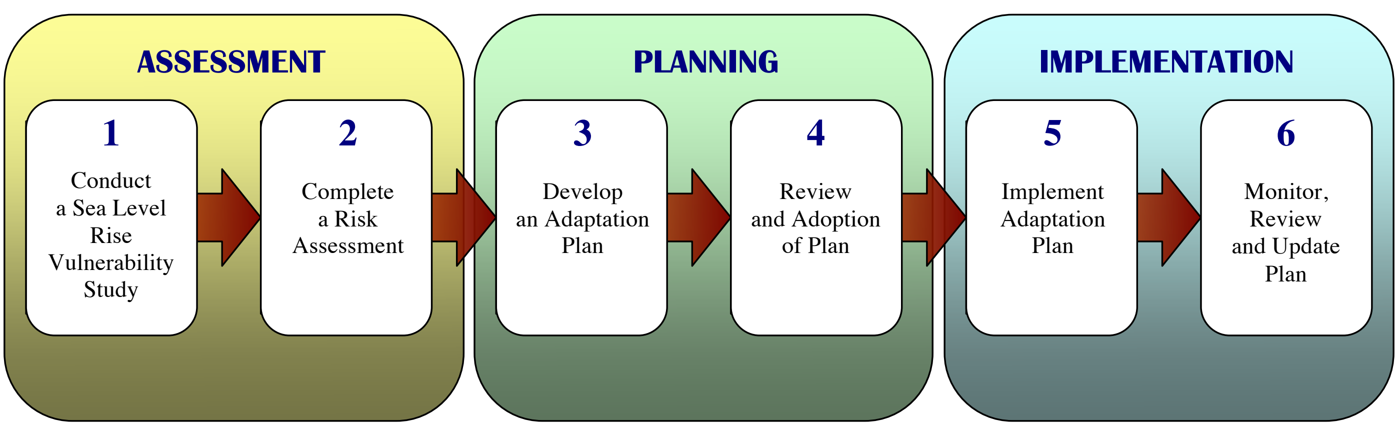


Figure 3.1. The components and steps involved in developing and implementing a sea level rise adaptation plan.

Task E. Identify and map projected impact areas for future sea level rise flooding and inundation.

Task F. Collect or obtain all data on historic coastal or shoreline erosion rates.

2. Complete a risk assessment based on the consequences of each hazard or process and the probability or likelihood of such an event occurring.

   Task A. Assess adaptive capacity

   Task B. Develop adaptation strategies

   Task C. Develop a risk assessment

3. Develop an Adaptation Plan
   a. Identify all adaptation options for each projected hazard.
   b. Specify the criteria for assessing each option
   c. Evaluate all options and develop recommendations
   d. Draft plan and complete internal review
4. Review and Adoption of Plan
   a. Review by individual agencies, the public and Planning Commission
   b. Prepare revised Draft Adaptation Plan
   c. Final review, editing and adoption by governing body (City Council, Board of Supervisors)
5. Implementation of Plan
6. Monitoring, Review and Update of Plan

After an adaptation plan has been prepared, reviewed by all of the appropriate agency staff, revised, edited and re-circulated, it will almost certainly need to be reviewed and approved by the local government Planning Commission as well as either the City Council or Board of Supervisors.

Plan approval may not be immediate or automatic. Presenting progress reports to elected officials, where emerging information and possible outcomes or recommendations can be discussed early in the process of plan development, may help to keep the final plan from being very controversial.

Following approval, it becomes the responsibility of the city or county planning department, or perhaps some other local government department or agency (city manager, public works department, for example) to implement the sea level rise adaptation plan. The adaptation plan will likely include policies that may require changes to existing land use plans (general plan, ordinances, zoning, etc.). When deemed necessary, based on future occurrences of hazardous events, changes in the rate of sea level rise or wave climate, and changes in community growth and development, the plan should be reviewed and revised or updated as deemed necessary.

CONDUCTING A COMMUNITY SEA LEVEL RISE VULNERABILITY ASSESSMENT

A vulnerability assessment constitutes the bulk of the effort in preparing for future sea level rise and related coastal hazards. The goal is to determine the areas most vulnerable to future flooding, inundation, and erosion from sea level rise and wave impacts. The following sections are presented in a step-by-step process and follow the outline on the previous pages.

Task A. Collect all Information on Community's Historical Vulnerability to Coastal Hazards

Every coastal community has a history of the impacts of past coastal storms, flooding, shoreline erosion and related hazards. There may be local summaries, reports, maps and often photographs on file in county planning, public works or other local agencies, but also photographic records and accounts or stories in local newspaper archives, natural history museums or libraries, or on websites.

Colleges or universities, state or federal agencies have often conducted post-storm or post-disaster investigations that have been assembled into reports or publications that can be very useful. Some of the most convincing evidence of the threats posed by future sea level rise and coastal storms are written accounts, maps of affected or damaged areas, or photographs of past events. Such records make it clear that these events have occurred in the past and will occur again, although most likely with greater frequency and intensity. Appendix B includes a listing of all of the major El Niño events to impact the California coast from 1912 - 1994 (Storlazzi & Griggs, 2000). This is a good starting point for checking on historical records or specific dates in newspaper archives to see what local impacts or damages may have resulted from these events.

Task B. Obtain Sea Level Information

Gathering historic sea level data is one of the most important steps in assessing vulnerability to future sea level rise. There are two components of sea level that are important to any individual city or county: 1] the extreme sea levels or tidal elevations that have been recorded in the past, and will likely occur in the future, 2] the long-term rate at which relative sea level is rising in your region.

The National Oceanographic and Atmospheric Administration (NOAA) provides current information about regional sea level, both extreme historic levels and also trends in sea level rise that come from its tide gauges. These combine data about ocean level fluctuations and vertical land motion at a number of locations along California's coastline. An important consideration in the use of these data is the time period covered by the closest gauge(s) to a particular community. The time period should be long enough (ideally 30-40 years or more) to distinguish short-term and decadal variations from long-term trends.

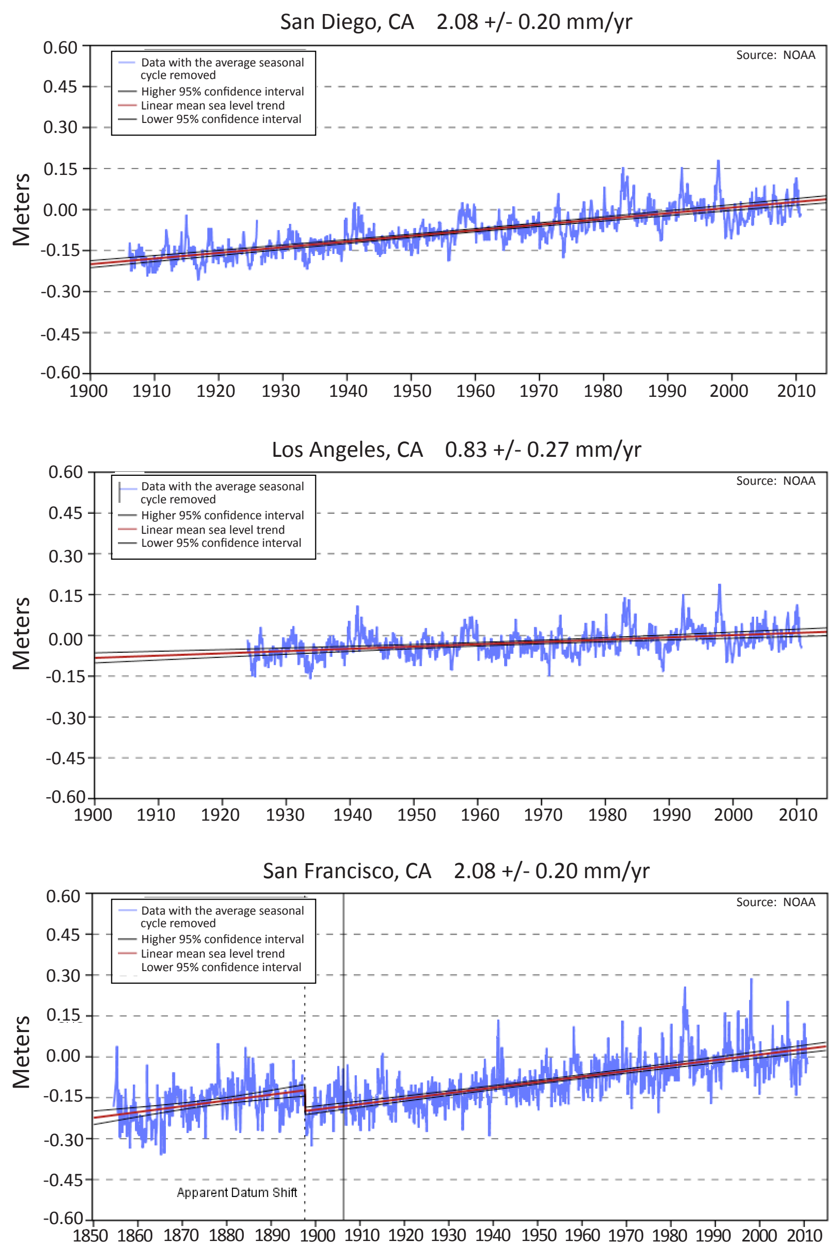
Visit: *http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca* to view local mean sea level rise trends for all NOAA tidal gauge stations in California.

While sporting goods store or surf shop tide tables provide reasonable estimates of the expected elevations of the high and low tides each day, up to a year in advance, a number of oceanographic or meteorological processes can raise regional sea level significantly above the predicted tidal elevations. El Niños, low atmospheric pressure, strong storms and large waves can all raise sea level above predicted elevations for hours to weeks (Figures 2.5 and 3.2). A subsequent section on Temporary Increases in Sea Level During El Niño Events or Storms will explain this in more detail.

Over at least the next 30 to 40 years, it is these short-term events that will likely present the greatest flooding and inundation hazards to coastal communities, rather than the more gradual long-term rise in sea level. The NOAA website for each tide gauge or water level recorder will contain information on the extremes recorded each year and how much they exceeded the predicted high tides at those sites.

The historic record of sea level change for each station can serve as useful minimum baselines or starting points for projecting future sea level changes. Unfortunately, not every coastal community has its own tide gauge, and some historic records are relatively short. Southern California has the most coverage and it once had five NOAA tide gauges between San Diego and Santa Monica, or one about every 30 miles on average (Table 2.2).

For the central coast, there is a 155-mile gap in coverage between Port San Luis and Monterey, (although there is only modest development in this area and the topography is steep and rugged), and another 125-mile gap between stations in Monterey and at the Golden Gate Bridge. There are three additional permanent tide gauges along the 422 miles of coastline between the Golden Gate Bridge and the Oregon border, or on average, one station for every 140 miles of coastline. Much of this area, however, is sparsely populated; development, with the exception of Crescent City and the Humboldt Bay area, is usually well above sea level on uplifted marine terraces.



Figures 3.2 a, b and c. Tide gauge records for California's three longest stations (San Diego, Los Angeles and San Francisco). Note elevated sea levels during major El Niño events of 1940 - 1941, 1957 - 1958, 1982 - 1983, and 1997 - 1998.

Determining Most Appropriate Tidal Gauge Data

For the many coastal communities that do not have local tide gauges, it will be necessary to determine which is the closest and most appropriate station to use. Overall, the differences in the rates of sea level rise along California's entire coastline for the past 50 to 100 years are quite small, however. The range of rates that have been recorded at 10 of the 12 stations, covering the 800 miles from San Diego to Point Reyes, range from 3.1 to 8.3 inches/century (0.75 to 2.10 mm/yr) (Table 3.1 and Figure 2.6). Therefore, for most communities, using rates of sea level rise from the closest station or stations, at least for the next 25 to 50 years, does not present major concerns. One additional consideration (depending upon a community's distance from a NOAA tide gauge and its exposure to sea level rise), is whether it may be advisable to work with NOAA to have a tide gauge installed in the community in order to begin to monitor sea level and how it is changing over time.

Komar et al. (2011) recently completed an assessment of sea level variations along the Pacific Northwest coast from Humboldt Bay in northern California to Neah Bay on the Olympic Peninsula in Washington. They relate differences in sea level records to changing climate and differences in land motion, whether uplift or subsidence. For the northern California coast, this work provides some regional perspective about how the elevation of the coastline has changed over time and, therefore, how local sea level rise has been affected.

Task C. Obtain Projections for Future Sea Level Rise

Although predicting the future always involves uncertainty, a community will nevertheless need to consider the potential for future accelerated rise in global sea level to affect local sea level trends. Many climate scientists and research groups around the world have been working on improving methods and models for estimating future global sea level rise based on a range of greenhouse gas emission scenarios and therefore, future atmospheric and ocean temperatures. The continued warming of the atmosphere and oceans, as well as the continued retreat of mountain glaciers and melting of ice caps and shelves of Greenland and Antarctica, are all parts of the equation. Depending upon their responses to continued warming, they will affect sea level globally.

The California Ocean Protection Council and State agencies have adopted future sea level projections (Table 2.1). The various projections or models for future sea level rise produce similar results for 2030 (5 to 8 inches of global sea level rise), with increasing differences by 2050 (10-17 inches) and considerable divergence by 2100, (ranging from 31 to 69 inches, or 2.5 to nearly 6 feet) (Figure 3.3) This increasing divergence of values as we go further into the future is common with any extrapolation or projection, simply because of the uncertainties in both natural processes as well as human behavior and government decisions.

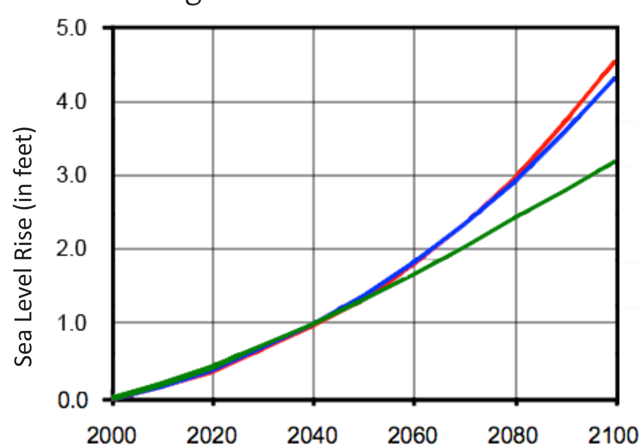


Figure 3.3. A range of projections for future sea level rise based on three different greenhouse has emissions and other scenarios.   Green = Low; Blue = Medium/High; Red = High (Adapted from Cayan, et.al, 2006).

The National Research Council's study is evaluating all of the factors that are expected to affect future sea level rise along the State's coastline and is developing up-to-date projections based on the best available information and science. Until then, for decision making involving planning, infrastructure or construction, state agencies are using the averages of the highest projected sea level rise values for 2030 (5-8 inches), 2050 (10-17 inches) and 2100 (40-55 inches). It is recommended that local communities use these projections in their planning until the updated values that will be developed by the National Research Council's Sea Level Rise Committee are completed in 2012.

When evaluating the possible consequences of global sea level rise for their community, a Team could handle the future uncertainty by performing a sea level rise hazards assessment by using a few different projected future sea level rise scenarios and different time frames. Planning Teams that are faced with limited resources, or for other reasons, may also consider the implementation of plans that allow for incremental adaptation, perhaps in 25 or 30-year increments, as sea level rise is likely to occur gradually.

Task D. Collect Information on Short-Term Increases in Sea Level, Exposure to El Niño Events and Changes in Wave Climate

Temporary Increases in Sea Level During El Niño Events or Storms

Short-term increases in sea level during storms or El Niño events will have greater immediate impacts and may be of greater concern to infrastructure and coastal development during the next 30 to 40 years than will gradual, more permanent sea level rise and inundation, barring very rapid increases in the rate of rise. Most of the major historic storm damage to California's coastline has occurred during El Niño storms, which were especially devastating during 1982-83 and 1997-98 (Figures 3.4 and 3.5).

Figure 3.4. Dune erosion threatening homes in the Pajaro Dunes area of central Monterey Bay during the 1983 El Nino.

Figure 3.5. Bluff top homes in Pacifica, San Mateo County, were undermined and ultimately demolished during the 1997-98 El Nino.

Sea levels along the state's coastline often rise substantially, ~12 inches or more (albeit temporarily), during El Niños, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened. The 1982-83 and 1997-98 El Niño events caused hundreds of millions of dollars in storm damage to private and public property as well as infrastructure, due to the combination of temporarily elevated sea levels and large storm waves, which in 1983 repeatedly coincided with high tides (Figure 3.6 and Figure 3.7; Griggs and Brown, 1998; Griggs, et al. 2005).

In late January 1983, sea levels were the highest that had ever been recorded in San Diego, Los Angeles and San Francisco, at 9.6, 12.2 and 18.7 inches above the predicted high tide levels, respectively. Gauges at Monterey and Crescent City also recorded the highest sea levels that had ever been reached at those stations. The magnitude and significance of temporarily elevated sea levels relative to long-term sea level rise are evident in the tide gauge records for San Francisco, Los Angeles and San Diego (Figures 3.2A, B, C). Adding these periodic El Niño changes to gradual sea level rise and high tides will present increasing risks for low-lying coastal development.

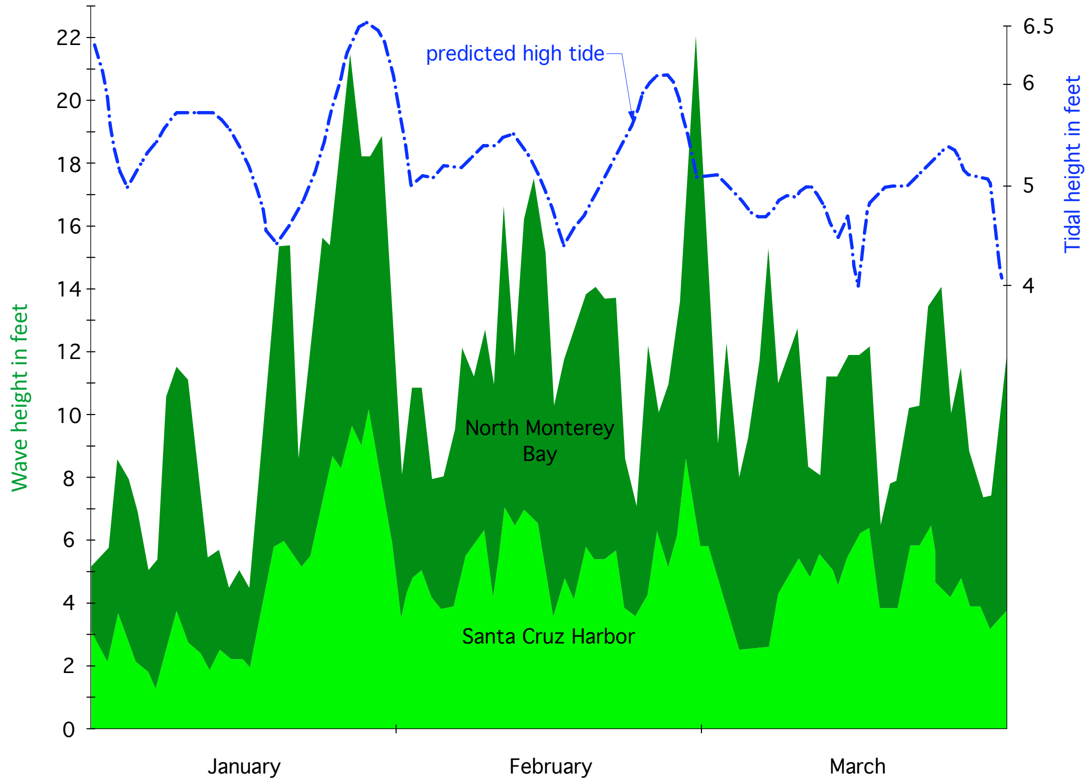


Figure 3.6. The arrival of large storm waves at times of high tides in the first three months of the 1983 El Niño produced millions of dollars in damage along the entire length of California's coast. Santa Cruz Harbor and North Monterey Bay are two different wave gauges. Predicted high tide is the higher high tide for each day.

Figure 3.7. Inundation of downtown Capitola by high tides, elevated sea levels and storm waves during the 1983 El Niño.

Collecting Historic El Niño Storm Damage Information

Most communities along the California coast were negatively affected by three El Niño winters: 1978, 1983 and 1997-98. There are statewide inventories of both impacts and damage (California Coastal Commission, 1978; Domurat, 1978; Swisher, 1983; Griggs and Johnson, 1983; Seymour, 1998; Storlazzi and Griggs, 1998). Local accounts typically are reported in local newspapers or are in the files of public works, planning department or other agency files. Maps, photographs, water level measurements or other information from past El Niño or other damaging coastal events should be collected and can inform the vulnerability assessment process. Those shoreline areas affected or damaged during past storm or elevated sea level events will most likely be the first to be affected during future incidents as sea level continues to rise (Figure 3.8).

Figure 3.8. Inundation of East Cliff Drive at Twin Lakes State Beach in Santa Cruz during elevated sea levels, high tides and storm waves in February 1998 (Photo: David Revell).

Changing Storm Climate and Increasing Wave Heights

While sea level has risen over time, average wave heights have also gradually increased during the last several decades along the west coast. Long-term wave data from buoys located off of the coasts of California, Oregon and Washington provide evidence of increasing offshore wave heights (Ruggiero, et al, 2010). While it is not yet certain whether these increased wave heights are related to warming of the oceans, there is a high probability that these phenomena are related. The causes for increased wave heights are not agreed upon yet, but they might include changes in storm tracks, higher wind speeds, increasingly intense winter storms, or other factors.

During the 22-year period from 1980 to 2002, the average wave height increased by 1.5 feet along the central California coast (Storlazzi and Wingfield, 2005). It is also important to keep in mind that these wave heights are based on the 22-year record between 1980 and 2002 but the trend is for increasing heights, so these values may continue to increase over time.

Seymour (2011) summarized evidence for changes in the Northeast Pacific wave climate by analyzing the number of occurrences of waves with average heights that were greater than 20 feet (6 meters). He divided the data into two 12-year periods (1984-1995 and 1996-2007) and found that for the area from Pt. Conception to the Oregon border, there is a substantial increase in the number of occurrences of these large waves between the first and the second time periods (Figure 3.9).

Changes in the wave climate along southern California (from Pt. Conception to the Mexican border) are less pronounced than they are along the central and northern California coastline. In the 1984 to 1995 period, there were 7 storm events with waves 16 feet or higher and 4 events that resulted in wave heights of 20 feet or higher. During the 1996 to 2010 period, however, there were 69 events that resulted in wave heights of 16 feet or greater and 10 events that resulted in wave heights of 20 feet or greater (Figure 3.10).

Coastal storms are expected to continue to increase in frequency and intensity during the coming decades (Barnard, et al, 2011). When increasingly large waves are combined with a gradually rising sea level, we can expect an increase in the frequency of the flooding of low-lying areas (Figure 3.11) and an increased risk and rate of coastal cliff retreat. Although wave characteristics may change in unknown ways in the future, their patterns over the past several decades have been well documented.

The effects of storm waves upon the coast are not new to California, which has been battered frequently during the recent past (Figures. 3.12 and 3.13). Rather, these effects are likely to be exacerbated by rising sea levels.

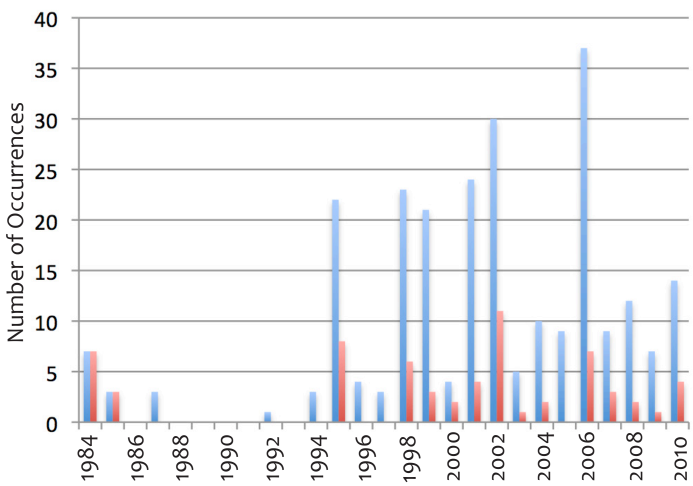


Figure 3.9. Increase in occurrences of waves with heights greater than 16 feet (shown in blue) and 20 feet (shown in red) offshore of northern California between 1984 and 2010.

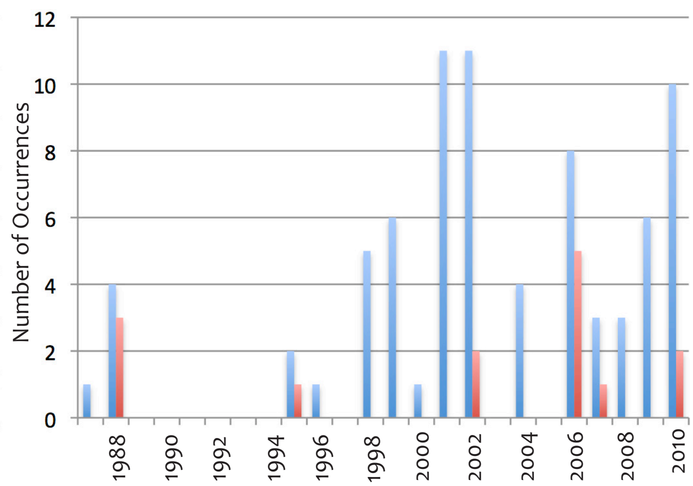


Figure 3.10. Increase in occurrences of waves with heights greater than 16 feet (shown in blue) and 20 feet (shown in red) offshore of southern California from 1984 to 2010.

Figure 3.11. Inundation of Beach Drive, Rio Del Mar, during 1983 El Niño.

Figure 3.12. Wave heights are increasing along the California coast (Photo of Santa Cruz Harbor Lighthouse by Shmuel Thayer).

Figure 3.13. Apartments on these cliffs at Pacifica were seriously threatened by wave attack during the winter of 2009-10 and 2010-11 leading to evacuation of the buildings and expensive efforts to try to stabilize the cliffs.

By establishing a baseline that shows how storm-related hazards have affected a community's shoreline planning areas in the past, a Team can begin to envision how increasingly severe or frequent hazards might affect the same areas in the future. It will therefore be better positioned to monitor and respond to those changes as they occur. Individual or community disaster memories often are short, and photographs or maps of historic damage or coastal flooding will serve as important reminders of past events for today's planning.

A useful initial step for any coastal community would be for the Team to compile its own history of coastal storm damage over the past 50 or 100 years in order to illustrate to elected officials, agency staff and others that the events to be expected during the future are not necessarily new, but they will most likely occur with greater frequency and intensity than in the past.

There are general databases of past storm history along the California coast that are helpful for such a compilation (see Griggs and Johnson, 1983; Griggs and Fulton-Bennett, 1987). Storlazzi and Griggs (2000) compiled a history of El Niño events that occurred during the last century. It provides a good starting point for a search of local records (newspaper archives, for example) to find evidence and documentation of historic storm damage. Appendix B lists the major El Niño events by their relative intensity or severity.

Task E. Mapping Exposure to Flooding and Inundation Associated with Long-Term Sea Level Rise

The next step in assessing a community's vulnerability to sea level rise is to map areas of potential future coastal flooding and inundation. The impact of future sea level rise is dependent upon the level of the ocean at various times in the future, the topography or elevation of shoreline areas, and the degree of development or amount of infrastructure.

Every California city and county has existing topographic base maps, which are used by many different agencies, planning, public works and building departments, for example. Typically, however, the contours on these maps are in two or perhaps five foot intervals, which is not a high enough resolution to display the areas that will be affected by future sea level rise that is being projected in inches or centimeters.

Precise elevation data are needed for delineating the areas likely to be impacted by different future sea level rise projections. A surveying method now exists that can provide the detailed topography needed to map the areas of a community that have a high for potential future flooding and inundation. LiDAR (Light Direction and Ranging) is a laser surveying technique with a vertical accuracy of 6 inches and a horizontal resolution of about 6 feet. There are both reasonably priced portable ground based instruments that can be used for surveying small sections of coast or shoreline, but also aerial LiDAR systems that are used by government agencies to survey large areas.

In 1997, when satellite observations indicated that a very large ENSO (El Niño Southern Oscillation) event was forming in the western tropical Pacific, federal agencies combined resources and collected aerial LiDAR data along most of the developed portions of the California coast in anticipation of the arrival and impacts of the El Niño. The pre-El Niño flight occurred in October 1997 and it was followed by a post-El Niño flight in April 1998. The data that were collected during those flights documented the extent of winter beach and bluff erosion with unprecedented accuracy over large stretches of the California coast. (*http://coastal.er.usgs.gov/lidar/AGU_fall98/*). This high-precision imaging of shoreline topography is available at no cost and allows a community to determine which shoreline areas are susceptible to flooding or inundation at various future sea level elevations.

In July 2010, the California Ocean Protection Council requested that NOAA collect and process new aerial LiDAR (Light Direction and Ranging) elevation data and imagery along the California coast. This project will produce an up-to-date, very high-resolution topographic map of the entire coastline, providing a permanent record of California's current coastal elevations.

LiDAR data will allow local Teams to access precise topographic data for their community and determine which areas are vulnerable to future sea level rise as well as sudden flooding from storm surges. Visit *http://www.csc.noaa.gov/digitalcoast/inundation/_pdf/guidebook.pdf* for a thorough guidebook about coastal inundation mapping. The USGS Center for LiDAR Information Coordination and Knowledge also provides useful information regarding LiDAR data at: *http://lidar.cr.usgs.gov/.* The topographic data from new flight will be available on a NOAA website in February of 2012. Downloading and using these data will require some experience with GIS (Geographic Information Systems).

Potential Beach Loss From Future Sea Level Rise

One of the important impacts of future sea level rise on those coastal communities that have recreational beach areas will be the gradual loss of beaches that are constrained or fixed by back-beach barriers, such as seawalls, revetments, roads, parking lots, buildings, or other structures. In the absence of a barrier, such as along an undeveloped stretch of coastline, a beach, along with its backing dunes or bluffs, would be able to retreat landward with sea level rise. Many of the state's urbanized beaches, however, are not free to migrate landward. Thus, progressive loss of beach areas can be anticipated depending upon the future rate of sea level rise and whether any action is taken to prevent beach loss (Figures 3.14 a/b and 3.15 a/b).

While such a beach may not physically erode, it will gradually narrow at a rate that depends upon the width and elevation of the beach and the height of sea level at specific future dates. The actual response of any individual beach that has a fixed barrier will likely be more complicated than simply raising water level over a beach with today's topography. A rising sea and wave runup will push sand landward and gradually raise the beach elevations. Nonetheless, projections can be made for any specific beach area where precise elevations exist by using these data.

If there is an adequate supply of sand and there are no back-beach barriers, or if back-beach barriers are removed, then any beach can migrate landward with future sea level rise as it has for thousands of years.

Figure 3.14a. Main Beach in Santa Cruz is visited by millions of people each summer, but is backed by a continuous concrete sea wall such that it cannot migrate inland with sea level rise.

Figure 3.14b. Main Beach during the El Niño winter of 1998 with waves reaching to the seawall at the back of the beach (Photo by Kristen Brown).

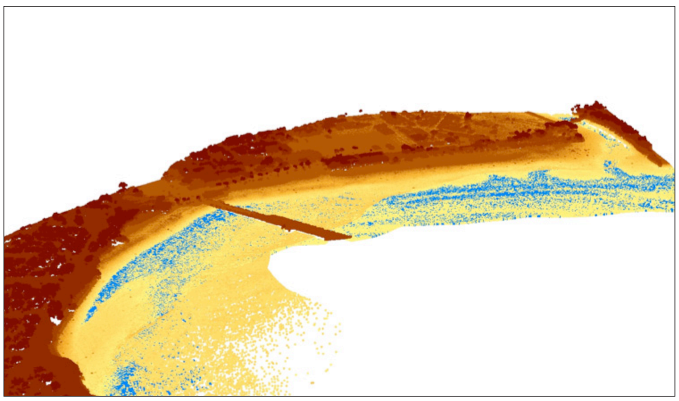


Figure 3.15a. Main Beach, Santa Cruz 2008. Blue indicates areas covered by water at mean high tide (Topography based on October 1998 LiDAR data).

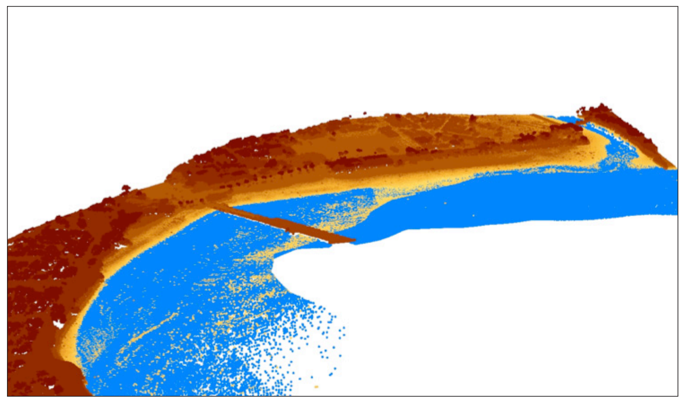


Figure 3.15b. Main Beach, Santa Cruz. High sea level rise scenario: 3 feet by 2100 (Topography based on October 1998 LiDAR data).

Task F. Documenting Historical Coastal Retreat and Assessing Future Risks from Increased Cliff, Bluff and Dune Erosion

Erosion along the coast of California can take several different forms. The beach erodes seasonally, but this is a reversible process and the beach sand that is lost each winter is usually replaced the following summer (Figures 3.16a and 3.16b). Where a wide sandy beach existed historically but present sand supplies have been significantly reduced through the construction of dams, debris basins or other sediment trapping structures, or through sand mining, the beach can be permanently eroded or narrowed. There is a general concern that some southern California beaches may be undergoing long-term erosion owing to sand supply reduction. However, if the sand supply or sand flow is restored, the beach may be rebuilt and it may recover.

Coastal erosion, in contrast, is the actual landward retreat of a coastal cliff or bluff. Normally the word "cliff" is used to describe a landform that is high, steep and consists of resistant rock (Figure 3.17), whereas bluffs tend to be lower, more gently sloping and consist of weak or unconsolidated material (Figure 3.18).

Figure 3.16a. Main Beach in Santa Cruz during typical summer conditions.

Figure 3.16b. Main Beach in Santa Cruz during 1978 El Niño winter.

Figure 3.17. Steep rocky cliffs at Laguna Beach, Orange County with no fronting beach (Kenneth and Gabrielle Adelman, California Coastal Records Project).

Figure 3.18. Moderately steep sandy bluffs at Manresa State Beach, Santa Cruz County, fronted by a wide sandy beach.

The process of coastal erosion is distinct from beach erosion, because cliff and bluff erosion are irreversible, at least by natural processes within human timescales. The rate at which a cliff or bluff erodes depends on several different factors: 1] the rate of regional sea level rise; 2] the amount of wave energy reaching the particular stretch of cliff or bluff; 3] the physical properties or strength of the materials that make up the cliff or bluff; and 4] the terrestrial processes that lead to cliff or bluff degradation and failure, such as runoff and gullying, slumps, slides, and earthquakes. The rate of coastal retreat depends upon the balance of all of those forces that act to break down or erode the cliff, and the resistance of the cliff or bluff materials to those physical forces or processes.

Coastlines that consist of hard crystalline rock (e.g. granite) such as along the Monterey Peninsula, or the outer end of Point Reyes, usually erode very slowly. In contrast, erosion rates can be high where the coastline is made up of relatively weak sedimentary rock such as sandstone or shale, or unconsolidated materials.

Coastal cliff retreat is one of the most dramatic processes taking place along the coastline. Collapsed roadways, undermined foundations, dangling decks and stairways and structures that have collapsed onto the beach are harsh reminders of the ongoing retreat of the California coastline (Figure 3.19). Many coastal communities have lost entire oceanfront streets through continuing erosion over the years and there are also many former lots that now lie beneath the waves (Figure 3.20).

Figure 3.19. Undercut apartment buildings in the Isla Vista area of Santa Barbara County (Kenneth and Gabrielle Adelman, California Coastal Records Project).

Figure 3.20. Bluff retreat in Pacifica during the 1997-1998 El Niño led to the loss of an entire row of oceanfront homes (Kenneth and Gabrielle Adelman, California Coastal Records Project).

Much of California's oceanfront development on cliffs and bluffs took place following World War II, from the 1950s to the 1970s. Coincidentally, low rainfall, a reduced severity of coastal storms, and a decreased number and intensity of El Niño events characterized the weather during these years (a period now recognized as a cool or negative Pacific Decade Oscillation phase; Figure 3.21). Thus, construction took place under the best of climate conditions. The severe 1978 El Niño, which surprised many oceanfront homeowners, produced widespread coastal damage and ushered in a warm or positive Pacific Decadal Oscillation weather phase, which continued until about 2010. This recent phase produced a number of additional damaging coastal winters: 1982-83, 1991-92, 1997-98 and 2009-10, for example.

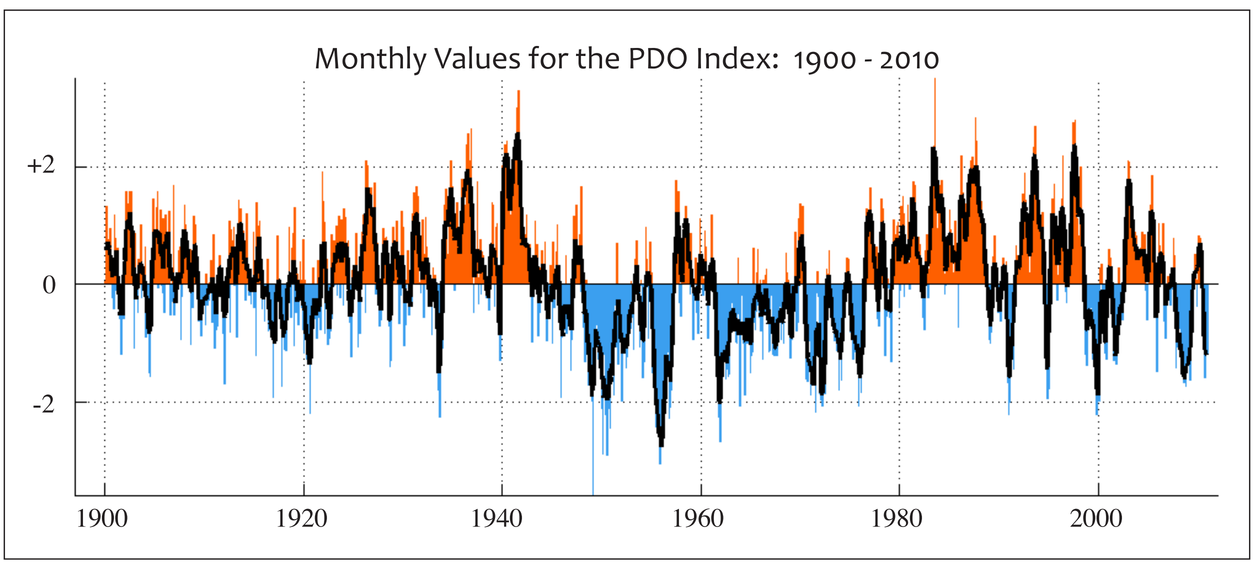


Figure 3.21. Pacific Decadal Oscillation (PDO) cycles for the past century. The vertical axis, or PDO value, is a dimensionless number, which combines a number of oceanographic and atmospheric parameters. The red or positive PDO values are periods generally characterized by warmer ocean water, heavier rainfall, more frequent storms and larger waves, and tend to produce more severe El Niño events. The blue or negative PDO values correspond to cooler water, lower rainfall, fewer and less intense storms, and tend to produce more La Niña events.

The interaction of the physical processes that produce cliff erosion or retreat, (i.e. wave impact, rainfall and runoff, earthquakes, etc.), with the different types of rocks that are exposed along the coast, has resulted in wide-ranging erosion rates along California's 1,100-mile coastline. At some sites, such as the Monterey peninsula, cliff erosion has been negligible for the 75–100 years because the granite is very hard and resistant to wave attack. Ten miles north along the sandy bluffs of southern Monterey Bay, the average rate of retreat ranges from two to seven feet per year. In general, weak sedimentary rocks such as the sandstone, siltstone, mudstone and shale that form much of California's coastline, retreat at long-term average rates of a few inches to a foot or more per year.

Coastal erosion tends to be episodic, however, with much of the long-term cliff and bluff failure taking place during a few severe storm events every 5 or 10 years. The arrival of large storm waves at times of high tides and elevated sea levels, which frequently occur during major El Niño events, can produce severe coastal erosion in areas that were formerly thought to be relatively stable.

Although the average long-term rate of retreat of the cliffs in Capitola has been about one foot per year, large slabs may collapse overnight, moving the cliff edge back by 5 to 10 feet, followed by little change for a number of years (Figure 3.22). Short-term cliff erosion rates are often very different from long-term (30–50 year) averages and need to be viewed with caution (Lester, 2005).

Figure 3.22. Cliff failure on Depot Hill, Capitola.

A recommended starting point in assessing future coastal erosion hazards in a community is to compile all of the existing erosion information for your city or county coastline. There are several sources for these data, including both site-specific studies as well as regional or statewide compilations.

Most development or re-development proposals for cliff or bluff-top parcels in California are required to undertake geological and/or geotechnical investigations that evaluate cliff stability and retreat rates. These reports should all be on file in Planning Departments by parcel number and they could be assembled in a GIS base.

The California Coastal Commission recently completed a statewide project that compiled all of the coastal erosion data in their files from consultant reports into a single database. That information is publicly available on a CD and it provides a valuable resource of existing erosion rate data (Dare, 2005).

Living with the Changing California Coast (Griggs, et al. 2005), includes mile-by-mile hazard maps for the entire coast of California, including erosion rates where available. Geologists familiar with specific areas wrote individual regional chapters and identified and described specific hazardous areas.

Depending upon the extent of coverage of the existing erosion rate data for a particular city or county and the extent of undeveloped oceanfront land remaining, there may be a need for and value in performing a cliff erosion study in order to fill in any gaps.

Most coastal cities and counties are already well aware of the areas within their jurisdictions that are subject to cliff or bluff erosion problems. The municipalities probably already have building setback procedures or guidelines in place, as well as requirements for geological or geotechnical investigations prior to issuing building permits. A study of coastal hazard policies for the state's coastal cities and counties completed 20 years

Figure 3.23. Wide sandy beach provides a buffer to the backing bluff from wave attack and it will require a significant rise in sea level before such areas are exposed to direct wave attack (Kenneth and Gabrielle Adelman, California Coastal Records Project).

ago, however, determined that there was considerable variation in how local governments dealt with issues such as setbacks for cliff and bluff construction (Griggs, et al, 1992).

Each city and county should begin by re-evaluating their existing cliff and bluff setback requirements, and the historic erosion rate data to determine which parcels and structures are located within setback zones or areas likely to be affected by cliff retreat at specific future times (e.g. 2030, 2050, 2100).

A continuing rise in sea level combined with a significant increase in wave heights will almost certainly increase the rates of coastal cliff or bluff retreat that California has experienced during the past century. Rising sea level alone over time would exacerbate the effect of wave impact on cliff and bluff erosion. Waves will break closer to the coastline and will reach the base of the cliff or bluff more frequently, thereby increasing the rate of cliff retreat. Where bluffs or cliffs exist landward of wide stable beaches (Figure 3.18 and 3.23), the impacts of sea level rise will not likely be felt for some decades to come. Where there are no beaches and waves already break against the cliffs on a continuous basis, sea level rise is also not likely to have a significant near-term impact (Figure 3.17).

The cliff and bluff areas most likely to be affected by a rising sea level will probably be those that are now fronted by narrow beaches (Figure 3.19, 3.20 and 3.24). These beaches provide only modest protection, but waves reach the base of the cliff frequently enough such that retreat is usually a concern. Because erosion rate has been related to the amount of time the toe of a cliff or bluff is exposed to breaking waves (PWA, 2009), additional exposure is almost certain to lead to increased erosion.

Figure 3.24. Lack of a fronting beach leads to continuous wave attack. A small rise in sea level will in all likelihood have a significant impact on cliff erosion in such areas (Kenneth and Gabrielle Adelman, California Coastal Records Project).

Where cliff erosion data are available, future projections for coastal retreat could be made by extrapolating existing erosion trends, adding a safety factor proportional to expected future sea level rise and increases in storm wave heights appropriate for the particular region of concern. Because projected rates of sea level rise and projected increases in storm wave heights are moderate for the near term, extrapolation of current erosion rates is likely to be reasonable to at least 2020 or 2030.

Chapter 4

RISK ASSESSMENT

Once the Team has achieved a good understanding of the effects of historic storm damage and the possible effects of future sea level rise on its coastline, it can move forward with a risk assessment. After determining which phenomena and associated impacts are likely to cause the greatest losses, the Team can focus on those areas and specific assets (i.e. people, places/buildings/infrastructure and natural resources) that are most vulnerable to future sea level rise. The result should be a list of priority planning areas that are at low elevations, (within 10 feet of sea level, for example), or close to the edges of sea cliffs. However, every community's list will be unique, and it is up to the Team to decide which areas are of greatest importance or value. The Team should also determine how these assets are expected to change during the future (e.g., projections for growth and development, proposed projects, etc.), and what these changes mean in the context of sea level rise, since communities should avoid new construction or development in areas that are likely to be flooded, inundated or at risk in the future.

Because the exact extent of future sea level rise is uncertain, the vulnerability assessment could be scenario-based. A range of projections can be used for the hazards that are associated with sea level rise based upon the medium-high and high future projections that have been adopted by California's state agencies. A cautious approach is to hope for the best but plan for the worst and use high values for future sea levels. When planning for the future, it is important to note that global sea level rise resembles global population growth. Its curve has an increasing upward slope because all of the factors that lead to a warm climate and sea level rise (i.e. energy usage, fossil fuel burning, greenhouse gas emissions) are increasing and will likely continue to increase for decades to come. It takes a long time to reduce the slope, and while the projection chosen by a Team today may turn out to be too high for a given point in time, sea level will eventually reach that point.

ASSESSING ADAPTIVE CAPACITY

The final step in assessing risk involves evaluating a coastal community's adaptive capacity, because its vulnerability to sea level rise depends not only upon physical stressors to the local shoreline but also on the ability of affected areas to adapt to those changes (NOAA, 2010). The Team must determine which adaptation options are available while considering the likelihood that the highest projected sea level rise may prevail. (See the following chapter for information about adaptation strategies.) The types of effects to be expected as a result of sea level rise, the potential costs of adaptation, and the longevity of various adaptation options need to be considered as well.

Adaptive capacity may be described in terms of a community's ability to prepare for, respond to, and recover from sea level rise impacts. A Team should evaluate the following:

1. regulatory and planning capabilities (e.g., development restrictions, coastal management regulations, hazard mitigation, sustainability, shoreline management, post-disaster recovery/emergency plans, etc.);
2. administrative and technical capabilities (e.g., the number of sea level rise experts, planners, engineers, GIS and mapping resources and modeling capabilities, etc.);
3. fiscal capacity (e.g., taxes, bonds, grants, impact fees, withholding spending in hazard zones and insurance); and
4. infrastructure (e.g., flood and erosion control structures, evacuation routes and redundant water, wastewater and power systems) .

As with the determination of a coastline's vulnerability to sea level rise, it is helpful to use scenario planning when determining a coastal community's adaptive capacity. A Team should develop a range of plausible sea level rise outcomes (probabilities and consequences) based on multiple points in time (e.g. 2030, 2050 and 2100) and multiple sea level projections in order to provide a basis for further adaptation planning. It is recommended to use the projections for future sea level rise that are currently employed by California's state agencies: 5-8 inches by 2030, 10-17 inches of sea level rise by the year 2050 and 40-55 inches by 2100, or the values that will be developed by the National Research Council's Sea Level Rise Committee. Each completed scenario should include quantitative projections of future sea level rise and descriptions of the potential associated impacts and consequences.

DEVELOPING A RISK ASSESSMENT

After conducting a risk assessment, which includes both assessing the probabilities of the future occurrences of individual events and the magnitude of the consequences of the events, a Team will gain an improved understanding of how sea level rise may affect its coastline. The Team should be ready to prepare a risk assessment summary for the community's exposure to sea level rise and related hazards (Table 4.1a and b). Such a summary, which will serve to inform a community's adaptation efforts, should consider each of the following:

1. actual future threats or hazards of concern (i.e. flooding, inundation, cliff or bluff erosion, beach loss);
2. economic importance or value to the community of public facilities and infrastructure;
3. value and community importance of private development sectors, whether they be commercial or residential;
4. magnitude of impacts of future hazardous events;
5. timing or frequency of impacts from these events (how often they occur);
6. certainty of projected impacts to the degree that these are known or can be expected (e.g. if sea level reaches a particular elevation, certain structures will be flooded).

		Probability / Likelihood of Occurrence			
		Low	Moderate	High	Very High
Magnitude of Consequence	Low			Passive Beach Erosion	
	Moderate			Increase in Coastal Cliff/Bluff Erosion	Wave attack of coastal infrastructure and development
	High			Flooding of low-lying coastal areas	

Risk = Probability x Consequence

Short to Intermediate - Term Risk Ranking 2010 - 2050

		Probability / Likelihood of Occurrence			
		Low	Moderate	High	Very High
Magnitude of Consequence	Low				
	Moderate				Passive Erosion of Beaches
	High				Inundation of low-lying areas Wave attack of infrastructure and development Increase in Cliff/Bluff Erosion

Risk = Probability x Consequence

Intermediate to Long - Term Risk Ranking 2050 - 2100

Table 4.1. a. Example of short to intermediate term (2010-2050) and b. intermediate to long-term (2050-2100) risk analyses for a coastal community. Risks in red boxes are of the highest priority for adaptation action because they occur most frequently and will have the greatest consequences.

Chapter 5

DEVELOPING an ADAPTATION PLAN

Once the vulnerability and risk assessments are complete, they can be used as the basis for defining a specific plan of action. There may be more risks associated with sea level rise and associated hazards than most communities can respond to initially due to the lack of staff and resources. For such cases, it is best to focus on the highest priority sea level rise risks and associated planning areas that have been identified during the vulnerability and risk assessment. These may include the facilities or development at the lowest elevations, infrastructure that is critical for meeting the needs of the community, (such as sewage lines or pumping stations), or structures or infrastructure that are closest to eroding bluff or cliff edges. The highest priority facilities or structures may be different for government agencies than for private homeowners and it is up to a Team to decide which are most critical by using a risk assessment as described in the previous chapter.

Note: It is also important to conduct careful reviews of existing local policies and regulations in order to identify how to best incorporate adaptation plans when dealing with measures that will control development. In some cases, regulations or policies may already be in place and will simply need to be modified or strengthened. Most coastal communities in California already have Local Coastal Programs (LCPs), which are basic planning tools that are used by local governments to guide development in the coastal zone in partnership with the California Coastal Commission. Teams should revisit and revise their LCPs as necessary when including new sea level rise adaptation measures. For more information, visit *http://www.coastal.ca.gov/lcps.html* online.

The California Climate Change Center offers some general principles for adaptation planning: human life must be protected; development and protection of the coast should be governed by the principles of sustainability (i.e., meeting the needs of the present without compromising the needs of future generations); consideration should be given to equitable distribution and apportionment of costs and benefits of adaptation measures; and adaptation strategies should account for the distinct vulnerabilities of potentially affected subpopulations.

SETTING PLAN GOALS

After priorities (such as reducing risks to critical infrastructure from future sea level rise) are clearly identified, a Team can define its adaptation goals. Goals should establish desired endpoints by stating the preferred long-term outcomes of adaptation to sea level rise. Some examples of goals include the following (NRC, 2010):

1. a plan or time line for phased relocation of existing infrastructure or public facilities away from vulnerable areas,
2. site and design all future public works projects to take into account projections for sea level rise,
3. eliminate public subsidies for future development in high hazard coastal areas,
4. prioritize critical public infrastructure for retrofitting/protection (storm water/wastewater systems, energy facilities, roads, bridges, ports),
5. potential removal of barriers to landward migration of heavily used public beaches and estuaries/wetlands,
6. develop strategic property acquisition programs to discourage development in hazard-prone areas; encourage relocation; and allow inland migration of coastal habitats,
7. discourage placement of shoreline armoring and encourage alternatives, and
8. encourage sustainable forms of development (such as clustered or higher density development in low-risk areas).

PLAN OBJECTIVES AND ACTION MEASURES

It is important to note that the most successful long-term coastal management programs set unambiguous, quantifiable, time-bounded objectives, (in contrast to vague or open-ended goals). Specific geographic areas that are of the highest risk, (either due to their low elevations or proximities to retreating cliffs), should be mapped and delineated, and timelines should be established for actions that are based on agreed-upon conditions or thresholds. For example, by the time high tides reach a certain elevation, a relocation plan has been established and action is initiated. Furthermore, when a retreating cliff or bluff edge erodes to within a certain distance of a street, sidewalk, sewer or water line, a clear retreat plan has been approved.

The team should remember to focus primarily upon planned or proactive adaptation, as opposed to reactive adaptation. Reactive adaptation includes changes in policy and behaviors that people and organizations adopt after changes in coastal risks are observed or communities have already sustained damage. For example, as property losses from increasing wave heights and increasingly severe coastal storms and sea level rise increase in frequency, insurance companies will likely raise their rates or drop coverage altogether, resulting in a disincentive to live in hazard zones. This has already begun to happen along the hurricane-prone barrier islands that line the South Atlantic and Gulf coasts of the United States. The purpose of adapting to sea level rise, though, is to avoid such problems altogether by planning ahead for the future. In this way, planned adaptation is intentional, rational, and it aims to address the full range of sea level rise hazards such that it meets societal objectives.

The Team will find that many adaptation measures are not new to coastal planners or managers. Rather, they include familiar strategies and actions for responding to typical natural hazards that coastal communities have already experienced, such as flooding, coastal storm damage and cliff retreat. Viewing these measures in light of sea level rise, however, allows coastal communities the opportunity to be focused and strategic in anticipation of future changes. In fact, it is often the historical records or reminders, such as newspaper stories, photographs and maps of these past events that are the most compelling evidence of the risks that a community faces and that can provide the basis for the development of an adaptation plan.

A range of criteria may be used for selecting the best adaptation options for a particular coastal community. These include actual effectiveness, cost and benefit, ease of design and implementation, and public and political acceptability. Each potential adaptation measure should be reviewed individually using those criteria or guidelines. The Team should recommend to decision-makers the choices that are most likely to be successfully implemented. These may be the most cost-effective, easiest to implement, or most politically acceptable choices.

In addition, synergistic or combined impacts should be considered and in some cases, adaptation measures will yield the best results when combined with others (e.g., combining new construction setbacks with new building codes). The Team must also consider a community's budget constraints and try to estimate all implementation costs. An adaptation plan cannot be enacted if a coastal community lacks the necessary resources, so it is important to be realistic about current organizational capacity and whether it is adequate for implementing and managing multiple adaptation options simultaneously.

ADAPTATION STRATEGIES: UNDEVELOPED VS. DEVELOPED LAND

There are three different types of future planning or adaptation considerations for coastal properties in most cities or counties:

1. Undeveloped parcels that are considered or are zoned to be developable.
2. Existing unprotected development, including residential and commercial areas as well as infrastructure (i.e. streets, parking lots, parks, bike paths, sewer or water lines, etc.).
3. Existing development that has already been armored.

A Team should be aware of the different adaptation strategies that are available for both existing and planned future development. Some communities have highly developed coastlines, while others that have some undeveloped land could take advantage of the opportunity to address potential future issues proactively. Undeveloped land presents the easiest opportunity for planning ahead or adapting to future sea level rise when taking into account the very high probability of increased rates of coastal erosion.

Combining historical cliff or bluff erosion rates with the projected lifespan of any future development has been the most common method of determining a safe setback distance from an eroding cliff or bluff edge. However, an increased erosion rate or safety factor needs to be considered, although there is not yet an agreed upon statewide method or value for this. A conservative approach is strongly recommended. Considering the State-adopted rate of future sea level rise and high probability of inundation or increased cliff or bluff erosion, it is the responsibility of an applicant and/or their consultant to make a case for the safety of a proposed structure during its lifetime.

Possible strategies for new, planned development include mandatory setbacks to restrict development in vulnerable areas, required warning notices to developers and buyers regarding the potential impacts of future sea level rise or cliff retreat, smart growth and clustered development in low-risk areas, and the development of expendable or mobile structures in vulnerable areas. The word "resiliency" is often used to describe a possible approach to development or land uses in hazardous zones. While public lands such as undeveloped parks, parking lots, bicycle or jogging trails could be considered resilient, because they can recover after being flooded or covered with debris following large storms, it appears that very little private coastal development can be considered resilient or capable of withstanding rising sea level, inundation or wave impact without serious damage.

Existing but unprotected development along the coastline presents a different set of issues for consideration. While the most common historic response to coastal erosion has been the construction of coastal protection structures such as seawalls and riprap revetments (Figure 5.1), the California Coastal Commission has been increasingly hesitant or resistant to the approval of new structures unless a residence or primary structure is under immediate threat. Currently, about 11% of the entire coastline of the state has been armored, with a much higher percentage of the most highly developed sections of the coast protected. Thirty-three percent of the shorelines of the State's four southernmost counties (Ventura, Los Angeles, Orange and San Diego counties) are now armored (Figure 5.2).

Depending upon the amount of future sea level rise and future changes in storm wave climate, there may be some highly valuable structures or development that a community feels must be preserved or protected for as long as possible. Conversely, there may be other structures that are directly exposed to future hazards, but because of their locations, the difficulties of protecting them may make protection or preservation impossible. In such a case, a moving setback zone or some other progressive retreat approach may be the best solution for the long-term.

Protected properties or structures may be stable and safe for several years or several decades until their seawalls or armor are overtopped, outflanked or otherwise compromised. Again, there may be an entire range of conditions to be considered in such cases, but part of the adaptation planning process may include a mechanism or set of standards for dealing with existing protected developments. Following severe wave attack and damage, for example, is it feasible to repair or rebuild a seawall and for how long will a property or structure be safe? While these may be difficult assessments or decisions to make today, conditions will change in the near future, so each of these issues should be addressed now.

Figure 5.1. Ocean Harbor House condominiums in Monterey were built too close to an eroding dune face, which ultimately led to the construction of a massive concrete seawall for protection.

Figure 5.2 Most of the developed cliffs of the city of Encinitas have now been armored (Kenneth and Gabrielle Adelman, California Coastal Records Project).

ADAPTATION STRATEGIES: PUBLIC VS. PRIVATE PROPERTY

An additional issue to consider is the difference between public and private property. A local Team will probably find that dealing with private property can be far more difficult than dealing with public property. This may be an uphill battle, but in the long run, the costs of restricting or limiting new development in recognized hazard areas (such as eroding sea cliffs or low-lying areas subject to flooding or inundation) would be far lower than the costs of dealing with damaged or imminently threatened development.

For existing private development in vulnerable areas, strategies for addressing sea level rise impacts include:

1. Planned retreat or relocation incentives from high-risk areas. Establish mandatory rolling setbacks for any future development or significant redevelopment in areas that are likely to be affected by sea level rise or cliff retreat within the anticipated lifetime of the structure.
2. Develop a plan and policies and identify funding or tax incentives for purchasing or relocating existing structures out of areas that are subject to future sea level rise or cliff erosion.
3. Restrict the rebuilding of vulnerable structures that have been damaged by storms and/or damage due to sea level rise.
4. Evaluate presently armored areas to determine whether additional armor or retreat is the most practical long-term approach.
5. Reduce and eliminate dependence on armoring (although there may be some critical structures where armoring may provide short to intermediate-term protection until other solutions can be implemented).

For existing public infrastructure or community resources, whether they be roads, parks, parking areas, sewer lines or sewage pumping stations:

1. seawalls may provide short-term protection, depending upon their specific locations and elevations, but
2. removal and relocation or replacement strategies should be regarded as the most effective long-term solutions. Develop retreat or retrofit plans for existing infrastructure that is subject to future inundation.
3. Design and site all future city or county projects and infrastructure to account for sea level rise predictions based upon the projected lifespans of the projects.

The critical question for each facility or structure is: "Based on the consideration of all of the costs and benefits as well as the risks, at what point should a community take action?" A shoreline park or parking lot can be used intermittently for a long time with periodic winter inundation, but a sewer line or pumping station at beach elevation must be relocated or replaced well in advance of flooding or failure.

SUPPORT FOR THE ADAPTATION PLAN

Before developing final policies, the Team should ensure that is has the support of those who have the largest stakes in coastal adaptation, including those elected officials who must ultimately approve and stand behind the plan. Open public meetings can be used to educate the general public, coastal property owners and elected officials about the need for an adaptation plan by presenting the impacts and hazards of sea level rise, the history of past storm and flooding damage, future vulnerabilities, and options for recommended adaptation approaches.

Chapter 6

IMPLEMENTING the ADAPTATION PLAN

Many local government initiatives fail or encounter major barriers when making the transition from assessment and planning to implementation, but such challenges can be overcome. A Team may run into administrative, institutional and political challenges. When a measure requires regulatory decisions or when it must be implemented through agencies that share jurisdictions and responsibilities, for example, it cannot be assumed that there will be effective coordination and communication between all parties.

It is up to a broadly based Team, with members or involvement from key agencies and departments, to coordinate decision-making, financing and execution of the adaptation measures it chooses through discussions and a shared sense of purpose. In addition, adaptation measures with regulatory components and those that must be carried out uniformly or region-wide (e.g., setbacks, buffers, zoning, etc.) may grapple with ineffective regulatory agencies or departments that have limited or no ability to carry out enforcement. Under these circumstances, it may be necessary to strengthen legal and institutional frameworks.

DEVELOPING A COMMON UNDERSTANDING

It will be especially difficult to implement sea level rise adaptation plans if key personnel in the local government agencies or departments involved either do not understand the issues that are associated with sea level rise, or if they are not convinced that these are significant issues. One critical role of a Team is to develop a clear and common understanding of the issues that will affect its community and to come to a consensus on how it will move forward. Providing information about the impacts of sea level rise, the need for adaptation, and the actions that can be taken by individuals and by others inside and outside of their own agencies will show other planners and policy-makers how they can contribute to and benefit from adaptation efforts. This information should include an estimate of the costs of implementing adaptation measures, as well as a projection of the long-term costs of taking no action. However, even when such information is made clear for decision-makers, long-term planning in any community is difficult because elected officials normally serve for short terms and they may be hesitant to deal with issues that may not provide immediate benefits.

FUNDING ISSUES

Carrying out an adaptation plan requires funding, not only for its initial implementation but also for periodic updates, since sea level rise is not a process that will cease at a certain level or on a specific date in the future. Securing funding may be easiest during times when adaptation to sea level rise is required by legislation and already on the agenda of a local government or political body. Typically, most action or legislation regarding natural hazards takes place immediately following a large and damaging event and then "collective amnesia" sets in and other issues become higher priorities than sea level rise adaptation planning. Good examples include the 1989 Loma Prieta earthquake, and the tsunamis resulting from the 2006 earthquake in Sumatra and in Japan in 2011.

As time passes, funding for area-wide adaptation, for the execution of regulatory measures and for those measures requiring large capital investments and follow-up monitoring may be difficult to secure. Some responses to this challenge include tapping into existing complementary organizations, (such as coastal management programs), merging new adaptation policies with planned coastal development for resilience, and exploring the use of tourist or user fees.

MONITORING PLAN EFFECTIVENESS

One of the most important requirements for sustained long-term implementation is scientific credibility. For example, the general reasoning in favor of a setback or buffer zone must be backed by data analysis that compares past, current and projected future sea level rise trends and the resulting inundation for the areas of concern. A map that depicts the historic landward migration of a shoreline or bluff edge over time stands as clear evidence that the California coastline is not static or stationary, and that it is experiencing a process that will likely that will be amplified in the future.

Once policies are enacted, measures must also be monitored over time in order to determine their effectiveness, because stakeholders need to know whether the policies are fulfilling their intended purposes. This may be challenging initially because the rates of change (millimeters per year of sea level rise and inches or feet per year of coastline retreat) are still relatively small, and because it is difficult to determine whether increased wave heights or larger storms are due to climate change or just part of the normal range of conditions to be expected.

It will also be useful for a scientist or other technical person on the Team to keep up with the growing wealth of scientific and technical knowledge that is becoming more and more accessible. Beyond this, the Team should conduct periodic program reviews to ensure that neighboring communities are aware of one another's successes and failures. Local consultants or university research groups may also be contracted to conduct regular monitoring of affected planning areas in order to assess the effectiveness of the adaptation measures in light of rising sea levels, increasing wave heights and their associated impacts. From initiation of the sea level rise adaptation planning process to its completion, it can be challenging to keep stakeholders involved and engaged throughout the process, depending upon the team approach used.

In some cases, it may be possible and preferable to first implement small actions or incremental steps in the most vulnerable or hazard-prone areas that build support for a larger effort, rather than making drastic changes immediately. However, for actions requiring formal adoption by multiple entities, (e.g., special area management plans), it is best to treat the process as a major public policy formulation effort from the very beginning.

Finally, it is necessary for a Sea Level Rise Preparedness Team to ensure that adaptation measures are appropriate for the geographic area of its community and its specific issues and that the measures achieve their intended goals. Unfortunately, there are many reasons for the failure of even well-designed and fully implemented measures. Poor execution, overly conservative design and poor construction can all lead to failure. In order to avoid such pitfalls, the Team should engage an engineer and a geoscientist in the preparation of standards and formulation of designs while using a performance-based approach to policies and actions that focuses on outcomes.

Chapter 7

EVALUATING PROGRESS

In order to determine the effectiveness of a Sea Level Rise Adaptation Plan, a Preparedness Team must continuously track any actions taken as a result of the plan's implementation and evaluate its community's progress toward meeting its goals. Performing a regular review affords the Team an opportunity to make changes to the plan, its goals, or actions based upon lessons learned from its implementation and from updated sea level rise information. It will also allow stakeholders to see whether the policies of the Plan are fulfilling their intended purposes. Ideally, the methods for tracking and evaluation, whether by quantitative or qualitative measures, are designed prior to implementation and integrated with the Plan.

EVALUATING ADAPTATION MEASURES

One of the most critical considerations is whether the actions carried out by implementation of a Sea Level Rise Adaptation Plan decrease the community's vulnerability to sea level rise and its associated impacts as identified in the original Plan. Evaluating progress in terms of reducing vulnerability will be difficult initially because the impacts of a rising sea level and increasing storm wave climate may take years to become obvious or recognizable. With a short timeframe, it is also difficult to determine whether increased wave heights or larger storms are due to climate change or just part of the normal range of climate variability. In general, it is prudent to keep track of any unexpected problems, obstacles or delays associated with adaptation actions, as well as any unintended positive or negative consequences.

Another important consideration is that sea level rise preparedness is a long-term and continuous process. A Team must adjust its original assumptions as natural, social, economic and political conditions change. For instance, a Team will likely come across new scientific information or data that could improve and possibly change its understanding of its community's vulnerability to sea level rise. Science advisors should be consulted in order to determine whether new findings are relevant to the community and its adaptive capacity and whether they should influence changes in the Adaptation Plan.

EVALUATING TECHNICAL CAPACITY

In addition to monitoring and evaluating progress for adaptation measures, the Team should be able to determine whether its community's technical capacity to prepare for sea level rise has increased. The Team may identify the number of technical experts in its community (or outside science advisors) who provide guidance on the latest information about sea level rise impacts in priority planning areas. It could also track the regular use of ongoing forums for sharing the latest sea level rise impact information with key local agency staff, the business community and the general public. In addition, the Team should be able to show the degree to which sea level rise data is considered in decisions and preparedness actions for areas of high vulnerability. The Team can also determine whether there are sufficient resources (e.g., amount of available funds, etc.) in place for performing vulnerability and risk assessments, implementing preparedness actions and evaluating progress.

FULL-SCALE REVIEW

In addition to revising an Adaptation Plan along the way, it is good to plan for a full-scale review every five years or so, during which the latest vulnerability assessment is reviewed and necessary changes to priorities are made. These should be based upon observed changes, new sea level rise projections, recent hazards and damaging events, changes in exposure to hazards, changes in adaptive capacity, and completed actions. The updated Plan should include a status review of the actions identified in the previous version, as well as examples of successes, challenges and lessons learned.

SHARING RESULTS

As a Team improves upon its preparedness actions, it should share its results with appropriate local government staff, elected officials and the public. Transparency and accountability will help the Team and the public recognize that implementation of the Adaptation Plan achieves its goals. This will provide the city, county, state, and federal governments with solid evidence that a Team's actions deserve funding and political support. In addition, publicizing positive results and benefits can help to improve community partnerships, and provide a mechanism for sharing information on the effectiveness or benefits of the plan with other coastal communities.

APPENDIX A. DEFINITIONS

Adaptation: The adjustment of natural or human systems in response to actual or expected phenomena or their effects such that it minimizes harm and/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, taking advantage of opportunities presented 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.

Resilience: The ability of an entity or system to absorb some amount of change, including extreme events, and 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, 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.

APPENDIX B

Summary of major damaging storms along the California coast 1912-1995 (from Storlazzi and Griggs, 2000).
NOR – not observed or recorded.

YEAR	Relative ENSO Intensity	Number of storms	Heavy beach erosion	Flooding
1912	4	2	NOR	X
1915	0	2	NOR	NOR
1916	-1	1	NOR	NOR
1923	2	1	NOR	NOR
1927	4	3	X	X
1931	0	2	X	X
1935	1	5	X	X
1937	0	1	NOR	NOR
1939	0	1	X	X
1940	2	1	X	X
1941	4	3	X	X
1942	5	3	X	X
1943	2	1	NOR	NOR
1947	0	2	NOR	NOR
1948	1	1	NOR	NOR
1950	-0.5	2	X	X
1953	2	2	X	X
1954	-1	1	X	NOR
1957	3	1	X	NOR
1958	3	1	X	NOR
1959	0	1	X	NOR
1960	-0.5	1	X	X
1963	1	1	X	NOR
1965	3	1	X	NOR
1969	1	1	X	NOR
1972	4	1	X	NOR
1973	1	1	X	NOR
1977	1	2	X	X
1980	1	1	X	X
1982	5	2	X	X
1983	6	5	X	X
1986	1	2	X	X
1990	1	1	NOR	X
1992	2	2	X	X
1994	1	1	X	X

APPENDIX C. ADDITIONAL USEFUL RESOURCES

1. Adaptation Took Kit: Sea Level Rise and Coastal Land Use. Jessica Grannis, (October 2001), Georgetown Climate Center.
http://www.georgetownclimate.org/sites/default/files/Adaptation_Tool_Kit_SLR.pdf

This Tool Kit was prepared by a group of attorneys at Georgetown Law's Harrision Institute for Public Law and provides local and state governments and their citizens with practical knowledge to help adapt to sea level rise. The Kit offers a menu of generally used legal devices that can reduce future harm and losses. Although some approaches may require the cooperation of state or federal government, a strong theme of the Tool Kit is that local governments have significant legal authority and tools to plan for future changes. It also recognized that not all tools are available in or suitable for all communities, and so anticipates and supports choice of approaches by each local and state government.

2. California Ocean Protection Council Resolution on Sea Level Rise adopted on March 11, 2011
http://www.opc.ca.gov/webmaster/ftp/pdf/docs/OPC_SeaLevelRise_Resolution_Adopted031111.pdf

This resolution is based on the agreement reached by senior staff from 16 state agencies (the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) regarding future sea levels along the California coast and why state and local government agencies need to begin to develop sea level rise adaptation strategies and plans.

3. The Impact of Sea Level Rise on the California Coast. The Pacific Institute (2009).
http://www.pacinst.org/reports/sea_level_rise

This study includes a detailed analysis of the current population, infrastructure, and property at risk from projected sea level rise if no actions are taken to protect the coast. The report also evaluates the cost of building structural measures to reduce risk.

4. National Assessment of Shoreline Change Project: United States Geological Survey.

A. Historical Coastal Cliff Retreat along the California Coast, Hapke, C. J. and D. Reid (2007).
B. Historical Shoreline Change and Associated Coastal Land Use along Sandy Shorelines of the California Coast. Hapke, C.J., D. Reid, B.M. Richmond, P. Ruiggiero, and J. List (2006).

http://coastal.er.usgs.gov/shoreline-change/

These two reports are part of a nation wide shoreline change investigation that the United States

Geological Survey has been conducting for several years. Using historic maps, aerial photographs and more recent LiDAR surveys, but short and long-term rates of cliff as well as beach or shoreline changes have been determined. Because the studies cover California's entire 1100 mile coastline, the data are most useful for regional purposes, rather than a parcel by parcel application.

5. Strategies for Managing Sea Level Rise, Urbanist (November 2009)
www.spur.org/publications/library/report/strategiesformanagingsealevelrise_11010

This report by the San Francisco Planning and Urban Research Association is focused on climate change adaptation for the San Francisco Bay area. It includes a good discussion of sea level rise issues, a section on different strategies for managing sea level rise, and a set of recommendations for sea level rise planning in the San Francisco Bay area.

6. Littoral Cells, Sand Budgets and Beaches: Understanding California's Shoreline. Patsch, K. and G.B. Griggs (2006)
www.dbw.ca.gov/CSMW/pdf/LittoralDrift.pdf

A clearly written and well-illustrated summary of how California's coastline and beaches work, including sources, transport and sinks for beach sand, sand budgets and littoral cells and discussion of beach nourishment.

7. Introduction to California's Beaches and Coast, Griggs, G.B. University of California Press (2010)

An easy to read and well-illustrated book that includes chapters on: the geologic evolution of the state's coast; weather and climate change; sea level changes; waves and the beaches; and coastal erosion.

8. City of Santa Cruz- Climate Change Vulnerability Assessment, Griggs, G. and B. Haddad (2011).
http://www.cityofsantacruz.com/Modules/ShowDocument.aspx?documentid=21198

This appears to be one of the first climate change vulnerability assessments for a California community and includes a detailed section on sea level rise and associated coastal hazards and how they have impacted the city in the past and may change and affect Santa Cruz in the future.

9. City of Santa Cruz- Climate Adaptation Plan (2011)
http://www.cityofsantacruz.com/Modules/ShowDocument.aspx?documentid=23643

This Adaptation Plan was written in response to the Climate Change Vulnerability Study and provides a discussion of expected future climate change and then a series of recommendations for how the city of Santa Cruz can adapt to the climate change impacts, including sea level rise and coastal erosion and flooding.

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