

CITY OF SANTA CRUZ CITY CLIMATE CHANGE VULNERABILITY STUDY

Gary Griggs
Brent Haddad

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OBJECTIVES

The objectives of this study are to provide some perspectives on climate change, to delineate and evaluate the likely impacts of future climate change on the city of Santa Cruz, analyze the risks that these hazards pose for the city, and then recommend potential adaptation responses to reduce the risk and exposure from these hazards in the future.

AN INTRODUCTION TO CLIMATE CHANGE

Society's need to cope with changing climate and environmental conditions is not new. People have been adjusting to their environment since the dawn of civilization. Agriculture is one of the earliest examples: over the ages, farmers have repeatedly adjusted cultivation practices and bred new plant and animal varieties suited to varying climate conditions. In recent times, the development of floodplain regulations, insurance programs, wildlife reserves, drinking water reservoirs, and building codes all reflect efforts to stabilize and protect our homes, livelihoods, and food and water supplies in the face of a variable climate. However, for the past 10,000 years, climate has been relatively stable, and weather patterns have fluctuated within a rather predictable range. Our growing awareness that the earth's climate is changing, and that we are facing novel future climate conditions that will interact with and compound our current economic and environmental challenges, has created a new context and a sense of urgency for climate adaptation planning (NAS-NRC, 2010).

Climate *change* is moving climatic conditions outside the range of past human experiences. While previous experience in coping with climate *variability* or extremes can provide some valuable lessons for adapting to climate change, there are important differences between coping with variability and planning for climate change. Climate change has the potential to bring about abrupt changes that push the climate system across thresholds, creating novel conditions (NAS-NRC, 2010).

Adapting to change is fundamentally a risk management strategy, an insurance policy against an uncertain future. Managing risk in the context of adapting to climate change involves using the best available science to understand the likelihood of

climate impacts and their associated consequences, then selecting and implementing the response options that seem most effective.

Overall, future climate change impacts in the United States are very likely to include warmer average temperatures and more frequent heat waves, changes in precipitation patterns and severe storms, and rising sea level. There are three major sources of uncertainty in determining future climate, however, and these include: a) the natural internal variability of the climate system, b) the trajectories of future emissions of greenhouse gases and aerosols, and c) the response of the global climate system to any given set of future emissions.

Scientific consensus based on an overwhelming body of evidence indicates that global climate change is happening, that it is caused in large part by human activities, and unless urgent action is taken at all levels of government to both mitigate and adapt to it, people and our environment could experience increasingly serious and damaging effects in the decades ahead.

“The greenhouse effect has been detected, and it is changing our climate now”. - James E. Hansen, Chief of NASA’s Goddard Institute for Space Studies during a U.S. Senate hearing on global warming, 1998.

“We have to deal with greenhouse gases. From Shell’s point of view, the debate is over. When 98 percent of scientists agree, who is Shell to say ‘Let’s debate the science?’” - John Hofmeister, President of Shell Oil Co.

“There are three responses to climate change: mitigation, adaptation and suffering. We are already doing some of each. The only question is what the future mix will be. The more mitigation we do, the less adaptation and suffering we will have to do”. - John Holdren, Scientific Advisor to President Obama

PLANNING FOR CLIMATE CHANGE

Designing and implementing a Climate Change Adaptation Plan and developing policies pose significant challenges for local governments and there are many impediments. The options available to planning officials have become better defined over time as they have been studied—and in some cases, implemented—but adaptation planning continues to involve many uncertainties. These arise from the fact that every community is unique in its geographic setting and its people, and therefore faces environmental and social vulnerabilities that will differ from those of neighboring communities. Santa Cruz, for example, faces different issues than Scotts Valley or Watsonville. Understanding the nature of these vulnerabilities and their magnitude is part of the challenge of creating an adaptation strategy.

Planning staff and decision makers should understand the local impacts before they can decide on the best responses. Even when the potential threats are reasonably well understood, the somewhat distant timeframes involved in many climate change impacts can make it hard to formulate, approve and implement policies that affect activities taking place at the present.

For several decades, climate change adaptation has been neglected in the United States, perhaps because it was perceived as secondary in importance to mitigation of greenhouse gas (GHG) emissions, or perhaps more importantly because it would actually take attention away from mitigation by implying that the country can simply adapt to future changes. In addition, the topic of climate change and the discussion of options for responding have become much more highly politicized in the United States than in some other parts of the world. Arguments in the media over whether climate change is “real” and to what degree it has been generated by human activity have confused people about whether action is needed and whether their actions can make any difference. Further, there are frequent suggestions in the media that responding to climate change is “too expensive” or that the options available to limit emissions and adapt to impacts will have a negative impact on the U.S. economy.

Adaptations to long-term problems involve long-term investments and bring considerations of intergenerational equity and other social and economic factors into play that significantly affect the calculation of costs and benefits. The influences of climate change extend well beyond the election cycle of the typical elected representatives in the United States. Long-term adaptations must, therefore, hold some promise of short-term reward if they are to be attractive to decision-makers.

Climate changes are already underway within California and in Santa Cruz and are likely to increase in the years ahead. Expected changes to local climate include: 1] higher temperatures, 2] water shortages, 3] longer droughts and more flooding, 4] increase in wild land fires, and 5] sea level rise and larger storm waves.

There is a growing consensus in those communities that have developed Climate Action Plans that responding to climate change is not only the right thing to do, it is the only smart thing to do. We can hope for the best but should be preparing for the worst. Most of the measures that are recommended for action would be prudent even if climate change were not an issue. They will save both the residents and the community money energy and fuel costs, create a healthier, safer, more livable and sustainable community and will provide insurance or buffer from any potential changes.

We are at a point on a long curve or trajectory of climate change trends but individual scientists using different assumptions or models have generated different extrapolations for the various climate parameters (air temperature, sea level rise

rate, or precipitation, for example). The main uncertainties in determining future climate and listed earlier include: 1] natural climate variability, 2] the trends of future emissions of greenhouse gases and aerosols, and 3] the response of the global climate system to future emissions. These uncertainties are often evaluated by applying various climate models, which provide information at relatively coarse resolution. At best, however, climate models can only provide insights about the range of future possibilities.

Preparing and adapting to climate change is not a “one size fits all” process. Just as the effects of climate change will vary from place to place, so will the best responses and adaptations to those changes. Much depends on a region’s resources and existing infrastructure and governance. The depth of analysis and level of response to any individual climate change issue should be appropriate for the risk involved, which is related to the magnitude of the impact, the certainty of the occurrence and also the community’s vulnerability to the hazard.

LOCAL GOVERNMENT RESPONSIBILITIES

Municipalities are expected to pursue four goals regardless of the climate future:

- a. Fulfilling duties expected and required of municipal government. These include providing police, fire, water, waste collection and removal, emergency response, land-use planning and management, redevelopment investment, and other local services.
- b. Maintaining fiscal discipline in carrying out the roles of government. This means investing in short and long-term needs of government wisely, and adapting to changing needs and climate impacts as needed.
- c. Contributing to the quality of life of residents. This includes helping provide a pleasant, civil environment in which the City’s citizens and visitors can enjoy their lives, provide for economic opportunity, and preserve the natural and cultural benefits of the region.
- d. Carrying out its duties in ways that are legal and transparent to the public. This includes the holding of regular elections and following public disclosure and other laws.

Municipal government that runs well already has adaptive capacity built into it. Running well includes successful budgeting and budget oversight processes; clearly-defined duties of personnel, clear lines of authority and accountability; rainy day funds; and good communications systems within the agencies of government and among agencies, elected officials, and the public.

Climate change has the potential to impact how municipal agencies carry out their duties. Many of the challenges posed by climate change are already part of City planning, such as drought response and flood zone planning. Among the duties of

municipal agencies are to react to climate-related disasters, including the kinds of extreme events identified in climate change scenarios. At the municipal level, these kinds of events have not been recognized as being linked to climate change but rather are simply at the extreme end of existing planning scenarios. Climate change means that in some cases certain scenarios currently are not receiving sufficient emphasis and budget, such as fire risk reduction. The more basic point is that fundamental changes in the structure and function of municipal government are not needed to prepare for and adapt to climate change.

However, some changes and restructuring of priorities are needed. Six areas in particular deserve early municipal attention when planning for climate change.

1. Review and support for Department preparation for climate-related events. This could include expanding inventories of fuel or water, shoring up roads and regular maintenance of drainage systems in flood-prone areas, and increasing the frequency of emergency response planning and practice.
2. Refocus City priorities in light of what is known about climate change. This could include identifying new priorities or regions for city redevelopment efforts, such as pursuing funding to help residences and businesses whose basements are threatened by a rising water table.
3. Recognize how Departments within municipal government support each other during climate-related events. This includes such areas as coordinating police, fire, and water department response during a major fire event, or police, public works and water department coordination during a major flooding event.
4. Plan for inter-regional cooperation during climate-related events.
5. Engage in advanced private contracting for services that might be lost in the broader region during a climate-related event. This may include establishing contracts for first rights to call upon privately owned water trucks to deliver water in Santa Cruz during or following a drought or flood emergency.
6. Plan for communications with the public as well as other agencies about climate-related local circumstances and events including flood risks in specific parts of the city. The City of Santa Cruz is taking action to inform itself and to prepare for climate change but the City is not the sole source of information for its residents any more that it would be for other potential hazards such as flu epidemic risks or pest infestations.

All six of these categories have direct and indirect economic consequences. They cost money directly in terms of acquiring supplies and equipment that otherwise wouldn't be purchased, as well as salaries of employees engaged in these actions. Indirectly they cost money in terms of the time municipal employees allocate to climate change preparation that could have been spent working on other priorities.

In the case of adaptation planning, these costs are primarily a form of insurance.

With a smaller investment, one is protecting one's self from sustaining a far greater loss. Adaptation investments recognize that new conditions exist and that the investments are now in the best interests of the municipality.

Drafting and implementing an Adaptation Plan to protect the City from the impacts of climate change is a demonstration to existing and potential businesses and residents of the City's commitment to long-term quality of life and economic vitality. Climate change potentially threatens economic vitality and the cultural and natural history of regions, and the City's choice to prepare for climate change signals its intention to keep Santa Cruz a thriving city and sustainable community for decades to come.

VULNERABILITY ASSESSMENT

The following is an assessment of potential significant impacts of climate change for the city of Santa Cruz with an emphasis on how anticipated climate change may affect the people, infrastructure, property and development, economy, environmental resources and community health.

A. SEA LEVEL RISE

Sea level rise is probably the process that has generated some of the most obvious and visible effects in Santa Cruz historically and that will continue to produce some of the most significant impacts on the city in the decades ahead. A continuing rise in sea level will produce a range of hazards or impacts including inundation of low-lying areas, erosion of coastal cliffs, and intrusion into the lower San Lorenzo River accompanied by lateral infiltration of water beneath the downtown area.

Sea level rise will gradually inundate low-lying areas, which include all of the shoreline and beach areas along the city coastline that are presently closest to sea level. Areas of inundation will extend landward as a result of sea level rise. The greatest uncertainty is the rate at which this is likely to occur. This section includes an assessment of low-lying areas and their potential for future inundation at specific future times as a function of sea level rise rates and shoreline elevations, including a range of rise rates consistent with current models and other predictions.

Planning for the extent of future sea level rise needs to include the possibility and consequences of a specific level being reached at some future time and also the costs of adapting to that level.

1. Sea level and causes of changes in sea level

There are important distinctions between *global* and *local* sea level trends, which are necessary to understand in order to interpret the sea level history of any specific

geographic area and then to assess vulnerabilities.

2. Absolute or global sea level change

Just as the surface of the Earth is not flat, the surface of the oceans is also not flat, and this sea surface elevation is changing over short and long-term time periods. We often refer to *Global Sea Level*, or the average height of all the Earth's oceans. *Global Sea Level Rise* refers to the currently observed annual rate of rise. This increase is attributed primarily to changes in ocean volume due to two factors: the melting of ice and the expansion of seawater as it warms. Melting of glaciers and continental ice masses, such as the large ice shelves of Antarctica and the Greenland ice sheet, which are linked to changes in atmospheric temperature, can contribute significant amounts of freshwater to the ocean. Additionally, any increase in the overall temperature of the ocean creates an expansion of seawater (called thermal expansion), thereby increasing ocean volume and raising sea level. The *Intergovernmental Panel on Climate Change (IPCC) 2007 Report* estimates that the global sea level rise was approximately 1.7-1.8 millimeters per year (mm/yr) over the past century based on tide gauge measurements around the world.

Beginning in 1993 the Topex-Poseidon and then Jason satellites have been able to accurately measure sea levels from space without having to separate out the local land effects and have documented an average global sea level rise rate of ~3.3 mm/yr (+ or – 0.4 mm/yr) between 1993 and 2009 (**Figure 1**). This represents a doubling of the 1.7-1.8 mm/yr rate used by the IPCC for the past century.

3. Relative or local sea level change

Tide gauges measure *local sea level*, which refers to the height of the water as measured along the coast at specific locations. Water level measurements are referenced to stable benchmarks on land, and a known relationship is established. However, the measurements at any given station will include both global sea level rise and vertical land motion, such as local subsidence or uplift. Because the heights of both the land and the water are changing, the land-water interface can vary spatially and temporally, which is what tide gauges keep track of. Depending on the rates of vertical land motion relative to changes in sea level, observed local sea level trends might differ greatly from the average global sea level rise, and also vary widely from one location to another.

In the Mississippi River delta area of Louisiana, for instance, significant sinking or subsidence is occurring and local sea level trends reflect an increase or rise of over 10 mm/yr in some locations. In southeastern Alaska, on the other hand, because the landscape is still rebounding or rising as a result of the removal of a thick ice cover from the last Ice Age, local sea level is *dropping* relative to land at 10 mm/yr or more.

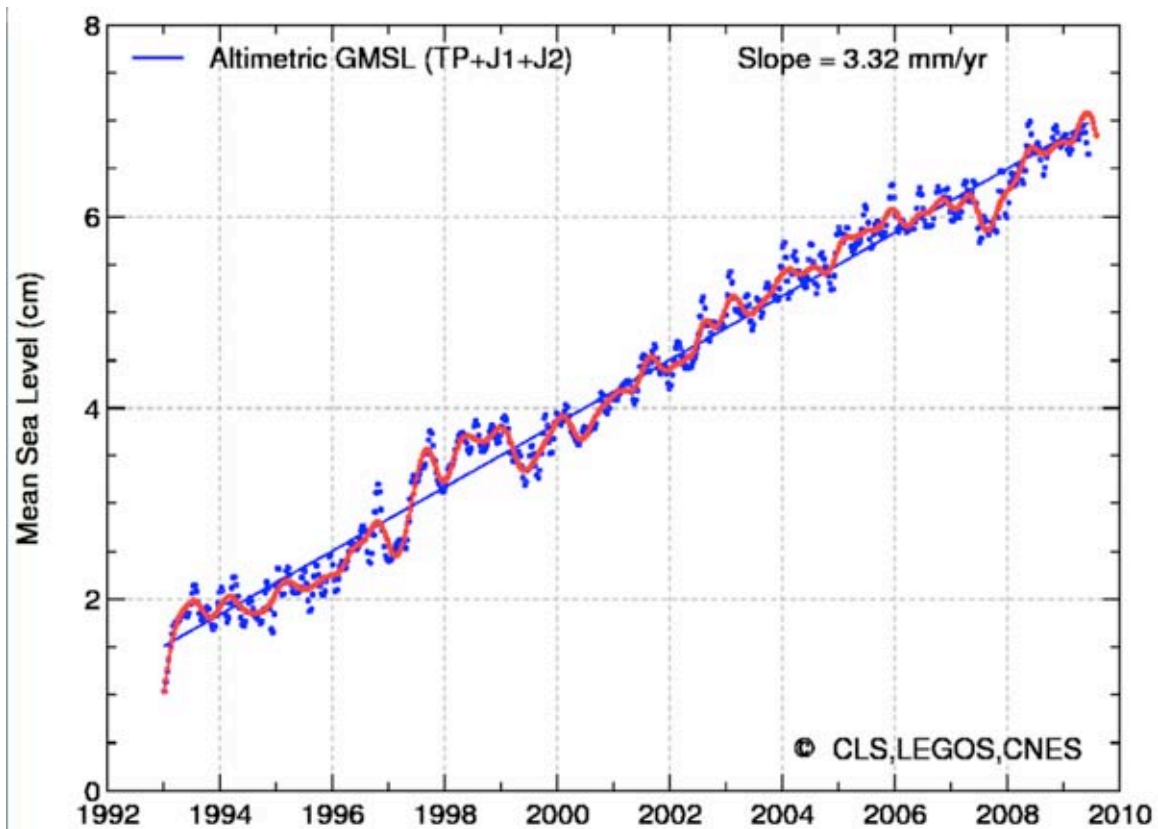


Figure 1. Global mean sea level rise from satellite altimetry.

Relative sea level trends reflect changes in local sea level over time at a particular location and are one of the most important factors that will influence sea level rise vulnerabilities and future coastal land use decisions.

4. Historic sea level changes along the California coastline

Sea level has been measured at 12 different California tide gauge stations extending from San Diego to Crescent City. Eight of the stations have at least 50 years of data, and the San Francisco station, the oldest, extends back to 1857. The local sea level rise rates at 10 of the 12 stations extending 800 miles from San Diego to Point Reyes range surprisingly little, from 0.75 to 2.10 mm/yr, or 3.1 to 8.3 in/100 years (**Figure 2: green diamonds**). These specific values are determined from the best graphic fits to the data, but there are significant year-to-year variations that need to be kept in mind. The two northern-most stations record the complex tectonic activity along the northern California coast offshore of Cape Mendocino where three large tectonic plates come together. At Humboldt Bay, sea level is rising at 4.73 mm/yr or 18.6 in/100 years (**Figure 2: yellow diamond**). Just 80 miles north at Crescent City, sea level is actually dropping relative to the coastline at 0.65 mm/yr or 2.5 in/100 years (**Figure 2: blue diamond**). The coastline at Humboldt Bay is subsiding and at Crescent City it is rising.

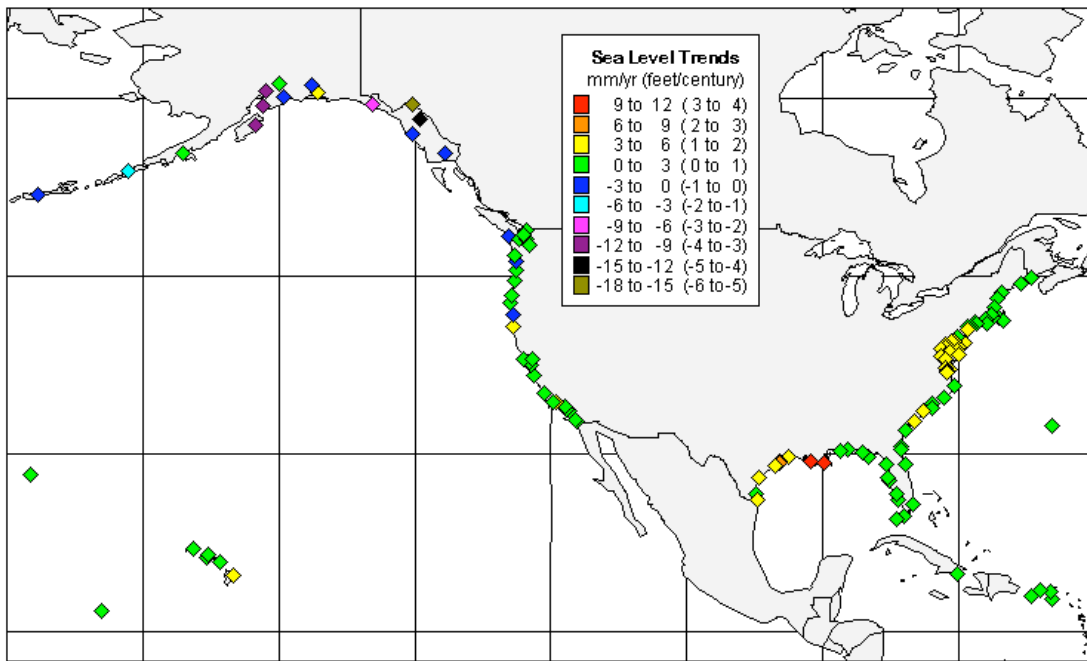


Figure 2. Sea level rise trends for coastlines of the United States

5. Santa Cruz Historic Sea Level Changes

There is unfortunately no permanent tide gauge station in the Santa Cruz area so we have to rely on other sources of information to estimate historic sea level rise. This is critical information to have, however, if we are to intelligently plan for future sea level rise along the city’s shoreline.

Recommendation 1. Partner with NOAA or independently install a permanent tide gage to begin to document local sea level change from this point forward. One possible location for the gage would be The Murray Street Bridge over the Small Craft Harbor.

The two closest tide stations are at Monterey, 37 miles to the south, and at San Francisco, 88 miles to the north. The Monterey station was installed in 1973 and the best fit of the data over this 36-year period indicates a rise of 1.34 mm/yr +/- 1.35 mm/yr with a 95% confidence interval (**Figure 3**). This is not a strong signal to rely on. The Monterey peninsula is underlain by granite, and is separated from Santa Cruz by the low relief, sediment filled flood plains of the Salinas and Pajaro rivers.

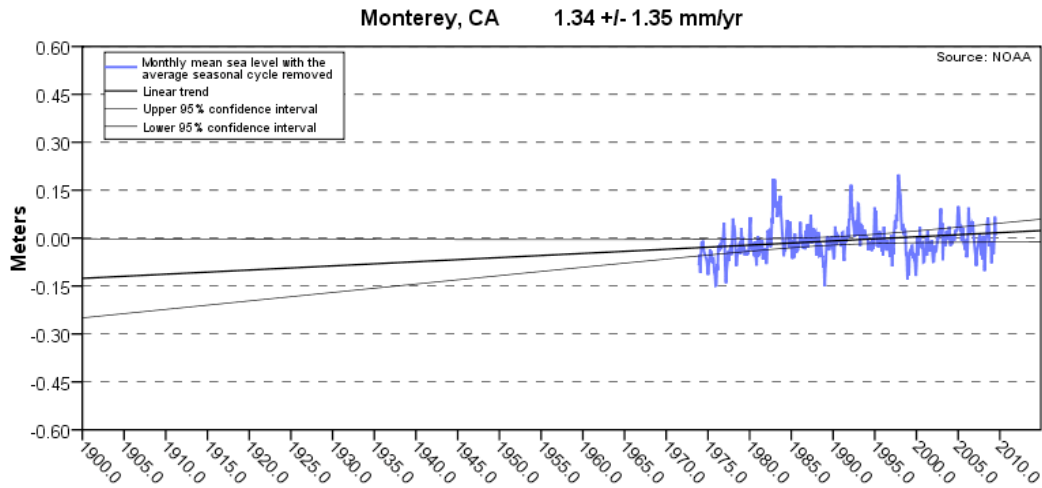


Figure 3. Mean sea level trend for Monterey, California

The San Francisco station is the longest running in California, extending back about 150 years and shows a sea level rise of 2.01 mm/yr +/- 0.21 mm/yr (Figure 4). This is a longer and more reliable record with less variance than that at Monterey, but it is on the opposite side of the San Andreas Fault on the North American plate. Despite being 115 miles apart, the sea level rise data are not that much different from each other, and not too different than most other California stations or the global value.

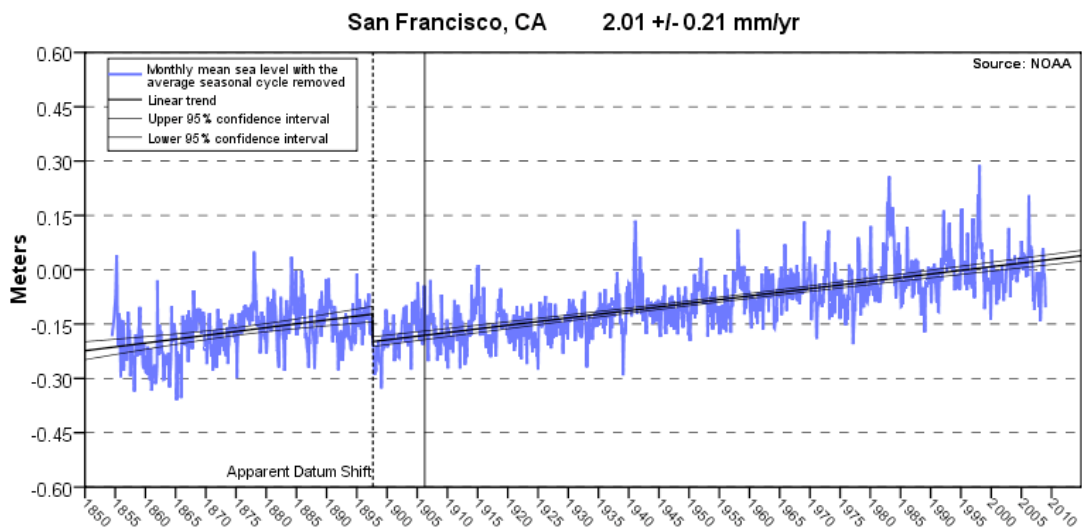


Figure 4. Mean sea level trend for San Francisco, California

Another approach to derive a local sea level rise value is to look at long-term uplift rates of the shoreline and combine this with global sea level rise data. Using the lowest marine terrace that underlies much of the city of Santa Cruz, and the uplift it has undergone since it was formed about 100,000 years ago, produces an average uplift rate of ~ 0.3 mm/yr. Using this value as a good approximation of the long-term coastal uplift rate, and using the 1.8 mm/yr global sea level rise rate of the past 100

years, produces a local sea level rise rate of about 1.5 mm/yr, a little higher than Monterey and a little lower than San Francisco, and slightly less than the global rate of sea level rise for the past century.

The determination of a sea level rise rate for Santa Cruz is complicated by the need to rely on tide gauges at Monterey or San Francisco, which may or may not be representative of northern Monterey Bay. Using average uplift data over 100,000 years produces a different but similar value. While satellite altimetry over the past sixteen years indicates an increase in the global rate of sea level rise, the Western Pacific has been rising at higher than average values, while the Eastern Pacific (the area off California) has actually dropped over this period. The tide gauges at both Monterey and San Francisco confirm this recent satellite observation, as do nearly all of the California coastal stations (**Figures 3 and 5**). Whether this recent change is due to differing water temperatures on opposite sides of the Pacific (with cooler water off California being denser, which would lower sea level slightly, for example), or results from the equatorial currents moving warm surface waters towards the western Pacific, or some other causes, is not presently understood or agreed upon.

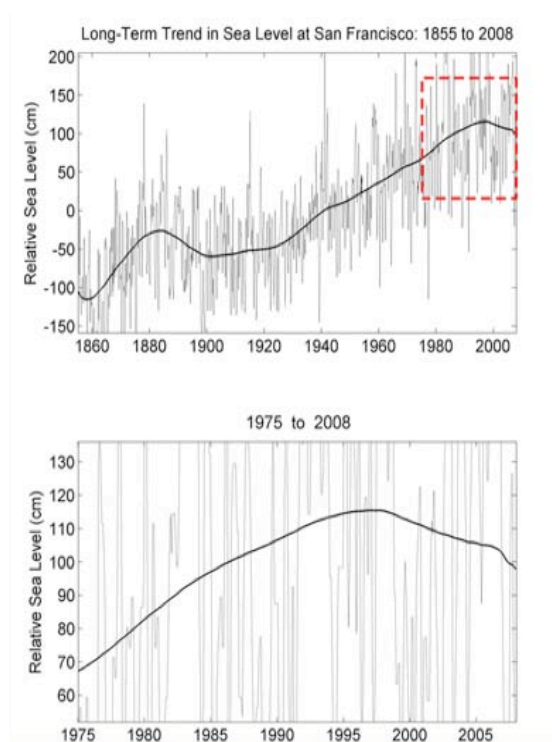


Figure 5. Long-term sea level trends at San Francisco (top) with the record of the last 33 years expanded (below).

6. Future sea level rise estimates

Global emissions of greenhouse gases have resulted in a general warming of the

atmosphere, which in turn heats up and expands seawater. Even when the atmosphere above the oceans is warm, however, it takes a long time for the oceans to warm and for sea levels to rise. This delay in response will result in sea levels continuing to rise for centuries. Even if global emissions of greenhouse gases were stabilized today, there would be continued thermal expansion within the oceans and melting of ice sheets and glaciers on land well after 2100. Therefore, infrastructure that has a long life, or developments that are considered permanent, will need to consider the implications of sea level rise for many decades to come.

Sea level measured over the past century at California tide gage stations has risen at an average rate of about 8 inches (20 cm)/100 yrs. Most recent assessments and climate models of future sea level rise project that both the rate and total sea level rise in this century may increase substantially above the recent historical rates. These projections are based on new scientific findings of the last several years suggesting that prior estimates likely have been too low.

By 2050, sea-level rise could range from 8 to 18 inches (20 to 45 cm) higher than in 2000, and by 2100, sea-level rise could be 20 to 55 inches (50 to 140 cm) higher than in 2000 (**Figure 6**). There is significant uncertainty in the upper bound because of uncertainties in the rate and amount of ice sheet melting, which has accelerated in recent years. Sustained warming could break up and melt the Greenland ice sheet, resulting in as much as 6.6 to 23 feet of sea level rise, although complete melting could take many centuries. The most recent (2009) California Climate Adaptation Strategy Draft Report prepared by the California Resources Agency uses the 20-55 inch sea level rise projection. In December 2010, the California Ocean Protection Council adopted recommendations for sea level rise from the state's Science Advisory Team of 5-8 inches by 2030, 10-17 inches by 2050 and 40-55 inches by 2100 for all state agencies.

Predictions of future sea level rise are regularly revised and updated as additional data are collected and climate modelers improve their understanding of complex atmosphere-ocean-land feedbacks, for example. Certainly our future carbon dioxide emissions will continue to be a major factor in future sea level rise responses and this is an area of great uncertainty (**Figure 7**). At the request of the Governors of California, Oregon and Washington, as well as the USGS, NOAA and the USACE, the National Academy of Sciences has initiated a study by a select Committee to determine the status of sea level rise along the coastlines of these three states, which should help resolve some of the uncertainties and differences in the values now being used. The first meeting of that Committee was held at the Seymour Marine Discovery Center at Long Marine Lab on January 12-13, 2011.

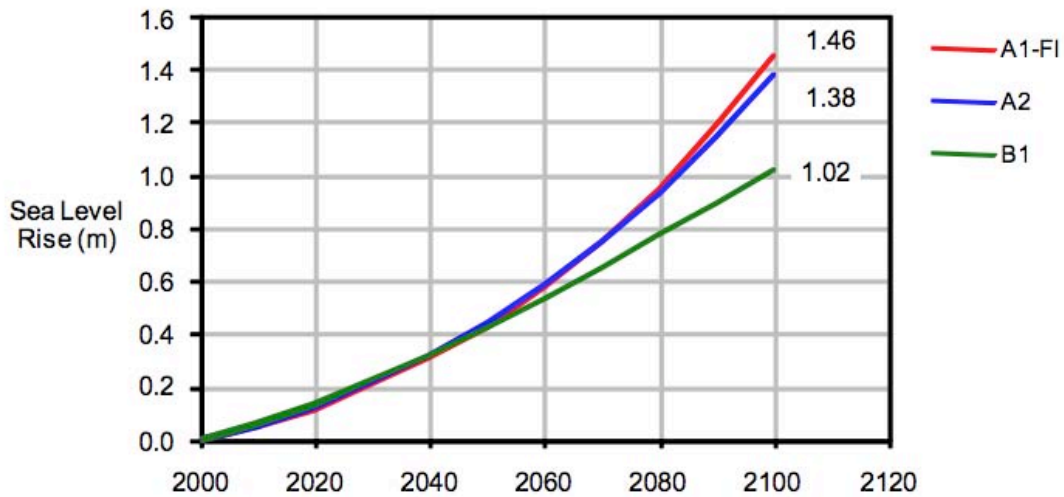


Figure 6. Sea level rise scenarios from climate model estimates for three greenhouse gas emissions scenarios: A1-fi (high emissions), A2 (medium-high emissions), and B1 (low emissions) from Cayan, et al, 2006.

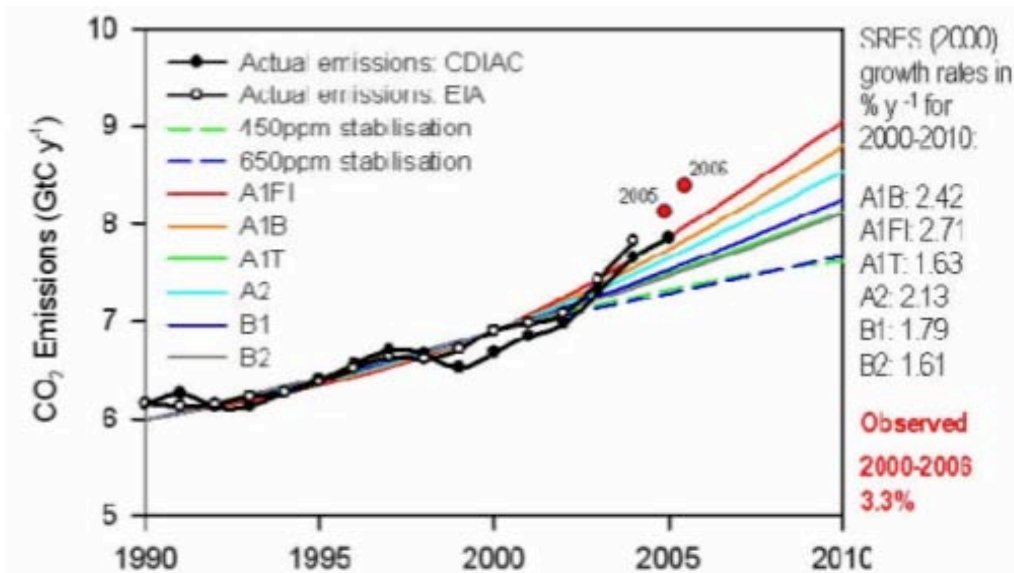


Figure 7. Historical and projected carbon dioxide emission scenarios, 1990-2010. Note that actual emissions (red dots) are exceeding all models.

As sea level rises, there will be an increased rate of extreme high sea level events, which can occur when high tides coincide with winter storms and their associated high wind wave and beach run-up conditions.

A recently completed study entitled *The Impacts of Sea-Level Rise on the California Coast* prepared for the California Ocean Protection Council (2009) 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 sea level rise scenario (**Figure 6**) was developed by the State of California from medium to high greenhouse gas emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) but does not reflect the worst-case sea-level rise that could occur. The report also evaluates the cost of building structural measures to reduce that risk. If development continues in the areas at risk, all of these estimates will rise.

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

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

The effects of a rising sea level can be exacerbated by El Niño occurrences. Sea levels along the California coast often rise substantially during El Niño winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened. A compounding element as the sea level rises is the continued occurrence of winter North Pacific storms, which elevate sea level due to wind and barometric effects, especially during high tides. Most of the major historic storm damage along West Cliff or in the Boardwalk area has been during El Niño events, and when storm waves arrive simultaneous with high tides and elevated sea levels (for example, the 1926 inundation of the Boardwalk).

There is also good evidence that wave energy along the West Coast has been increasing over the past several decades. Some researchers believe that continued ocean warming and global climate change may bring more frequent and severe El Niño events such as we experienced in the 1982-83 and 1997-98 winters. Were this to occur, the effects of a rising sea level would be exacerbated by increased wave energy impacting both low lying areas (such as Cowell's, Main Beach and Seabright Beach) but also the sea cliffs along the city's coastline.

Vulnerability of the Santa Cruz Coastline to Future Sea Level Rise

- a. West Cliff Drive-** The coastline extending from Long Marine Laboratory to Cowell's Beach consists primarily of 25 to 40-foot high cliffs that front an uplifted marine terrace. The cliffed coastline is broken up by small pocket

beaches, with Natural Bridges State Beach and Its Beach being the largest and most intensively used. Many of the other smaller pocket beaches are backed by riprap so that as sea level continues to rise, these narrow beaches will gradually narrow even further.

The areas of specific concern to the city with a continuing sea level rise and coastal erosion include the bike path, parking areas along West Cliff Drive as well as the road itself, the sewage pumping station near Almar Avenue, the bridge at Bethany Curve immediately west of Woodrow Avenue, Its Beach and Lighthouse Point. The key factors affecting the vulnerability of these areas to future risks or damage from sea level rise and wave attack include: 1] elevation, 2] sea level rise, and 3] wave climate.

- **West Cliff Drive and the Bike Path-** During conditions of high tides and large storm waves, such as occurred during the El Nino winters of 1983 and 1997-98, waves will frequently overtop local sections of the cliff between Woodrow Avenue and Lighthouse Point (**Figure 8**), which historically has led to cliff erosion and damage to parking areas, undercutting and collapse of the bike path, and sand and gravel being thrown up onto West Cliff and into the parking areas. Repairs have been made, new asphalt laid down, and additional riprap emplaced (**Figure 9**). With rising sea level and if wave conditions increase in severity, these conditions will occur more frequently with consequent increase in damage and erosion.

The elevation of the cliff top and West Cliff Drive range from about 40 feet from Natural Bridges to San Jose Avenue, decreasing to 30 to 35 feet from San Jose Avenue to David Way, and then reaching the lowest elevation just west of Woodrow at the Bethany Curve bridge where West Cliff Drive is only 25 feet above sea level. From Woodrow Avenue east and along Lighthouse Field elevations range from 37 to 38 feet, and then decrease to about 30 feet at the Lighthouse itself. Heading towards Cowell's, West Cliff increases in height to 50 feet approaching the Sea and Sand Inn. The hazards at specific locations along West Cliff Drive are discussed individually below.

- **Sewage Station-** While the sewage discharge line coming from Neary Lagoon passes through a pump station just below West Cliff Drive near the end of Almar Avenue (which also serves as a stairwell to the beach), this is a gravity flow system so there are no actual pumps that would be threatened with a rise in sea level. The sewage outfall discharges at a water depth of 110 feet so the treated wastewater flows by gravity from its origin in Neary Lagoon. There is therefore no near future threat to the discharge line from sea level rise in the foreseeable at this location.



Figure 8. Winter waves reaching the cliff top next to Lighthouse Point (photo by Shmuel Thayer)



Figure 9. Rip rap along West Cliff Drive (Photo California Coastal Records Project © Kenneth and Gabrielle Adelman)

- **Bethany Curve Bridge**-At an elevation of only 25 feet, the bridge over the drainage just west of Woodrow Avenue is the lowest point along West Cliff Drive and is frequently overtopped by white water, which washes kelp, sand,

gravel and other debris over the bike path and onto the roadway during large storms and high tides. At this location the water at high tide is only about 15 or 20 feet from the sidewalk and the low bluff is shaped like a ramp so that wave run-up can more easily overtop the bluff. Some riprap has been placed in this area but overtopping continues at high tide under the right storm conditions. Significant cracking of the concrete bridge has also taken place in several locations. A public safety concern exists here at present under high tide and large wave conditions and this will worsen as sea level rises and if wave heights also increase.

• **Lighthouse/Its Beach**- With the exception of Natural Bridges, which is a state beach, Its Beach is the most intensively used beach along West Cliff during the summer months. During the winter, storm waves lower the beach sand level and attack the cliffs at high tides. Monitoring of Its (Lighthouse) Beach during the 1997-98 El Niño documented that the 150-foot wide beach present in October was completely eroded by February and the sand had dropped about eight feet in elevation (**Figures 10a and b**). There is no armor backing the beach so as sea level has risen historically, the cliffs have gradually retreated, but a narrow and heavily used beach has persisted. Overall, the low cliffs have changed very little over the past century. A rising sea level rise will progressively narrow the summer beach and lead to more frequent and severe winter wave attack, which even now overtops the bluff (**Figure 8**).

b. Cowell's, Boardwalk and Main Beach Area- While the area from Long Marine Laboratory east to Cowell's is dominated by low cliffs and small, narrow pocket beaches, the area from Cowell's to the San Lorenzo River mouth is one long, wide, essentially continuous beach which is an intensively used recreational area. The Santa Cruz Beach Boardwalk attracts about 3 million people annually, and many of these visitors use Main Beach. There are two concerns with sea level rise for this area of shoreline: 1) gradual inundation of the beach and low-lying back beach areas, and 2) storm damage to oceanfront development or infrastructure.



Figure 10. (a) Its Beach in October 1997; (b) Its Beach in February 1998.

- **Cowell's Beach**- Winter waves and high tides during severe winters typically reach the back edge of Cowell's Beach. A seawall protects the front of the Dream Inn and a stepped concrete retaining wall extends from the Dream Inn to the wharf. The city parking lot at Cowell's is at an elevation of about 16 feet. There is therefore no immediate concern with storm wave damage in the near future, but because the back of the beach is fixed with a continuous concrete wall, the beach will continue to narrow as sea level rises.

- **Main Beach and the Boardwalk**- During El Niño winters with elevated sea levels and large storm waves, such as 1983 and 1997-98, Main Beach will be eroded with logs and debris from the San Lorenzo River deposited completely across the beach and up to the concrete steps in front of the Boardwalk (**Figure 11**). Storm waves during a severe El Niño winter in 1926 washed up and over the steps as well, so this isn't a recent phenomenon (**Figure 12**). Sand elevations in the summer at the base of the concrete steps and along the concrete seawall along Main Beach are about 10 feet. Beach Street and the Boardwalk are at an elevation of about 13 to 14 feet above sea level so won't be impacted immediately by rising sea level. However, storm waves at high tide and elevated sea level conditions have brought logs and debris to the base of the concrete wall, and a rise of several feet will lead to more frequent winter wave impact. Main Beach has its back edge fixed by a concrete retaining wall/seawall that extends from the pier to the river mouth, so that a gradually rising sea level will progressively inundate the beach in the summer as well as the winter. Regular overtopping of this wall will probably not occur until sea level rises at least an additional two feet. Three different sea level rise scenarios have been run on Main Beach in order to see what increases of one, two and three feet would inundate (**Figures 13 a, b, c, d**). Because the beach here is relatively flat, even a foot of sea level rise would cover much of Main Beach.

The former Fun Spot, now the location of the proposed Monterey Bay National Marine Sanctuary Visitor Center, is at an elevation of 12-13 feet. The inner edge of Beach Street near La Bahia is at an elevation of 13-14 feet, but this increases rapidly inland ascending beach hill. The area from Cliff Street (which passes in front of the Surf Bowl) to the San Lorenzo River, including both Boardwalk parking lots, and the businesses and residences from Beach Street inland to the San Lorenzo River are all at elevations of about 10 to 12 feet but are behind the levee, which is at elevation 16 feet at this location.



Figure 11. Main Beach during 1997-98 El Niño.



Figure 12. Waves washing up to the Boardwalk in 1926 El Niño storms.

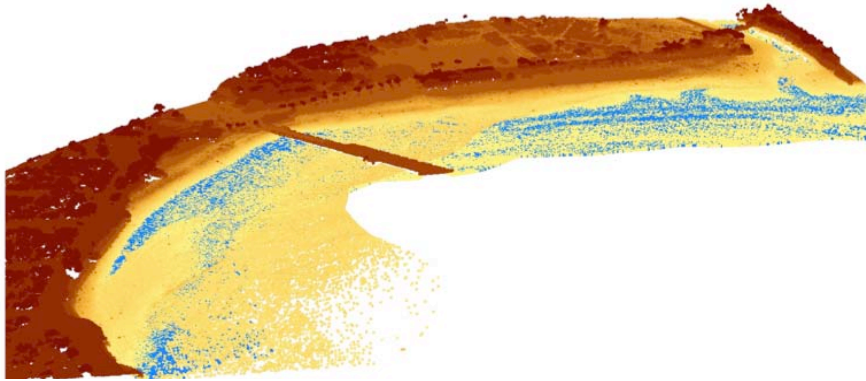


Figure 13a. Main Beach in 2008. Blue indicates areas inundated at mean high tide.

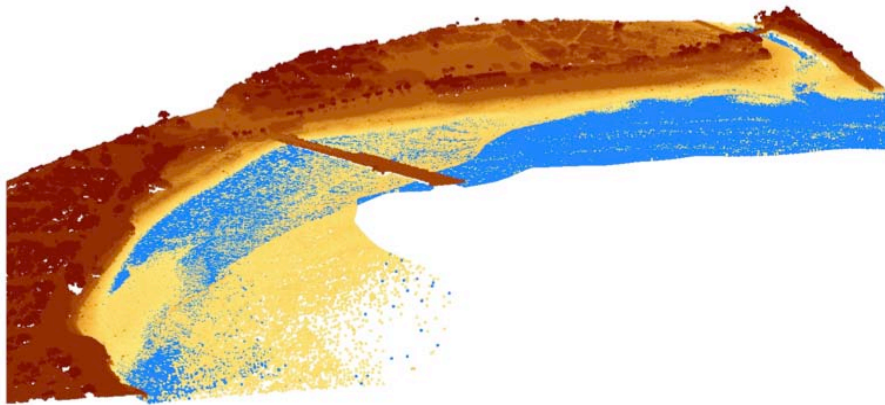


Figure 13b. Main Beach at mean high tide with low sea level rise scenario (1 ft by 2100).

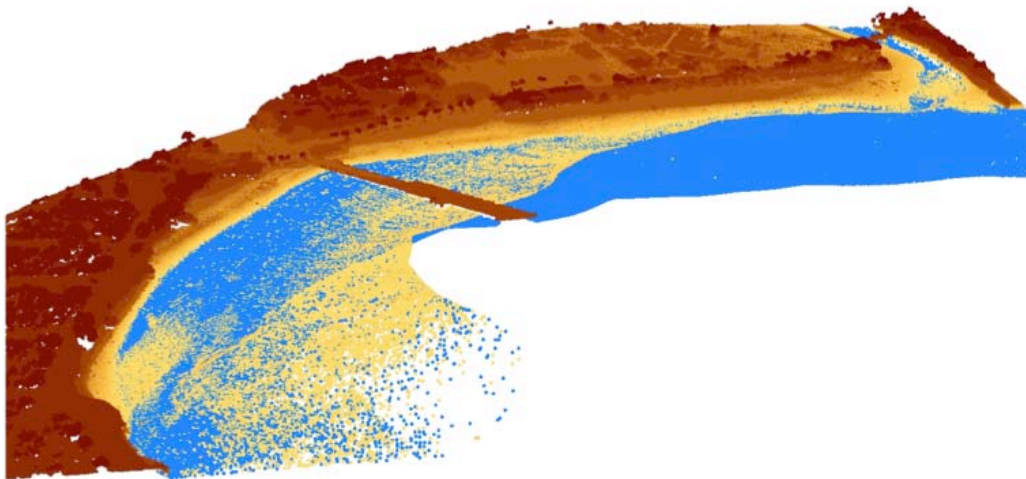


Figure 13c. Main Beach at mean high tide with medium sea level rise scenario (2 ft by 2100).

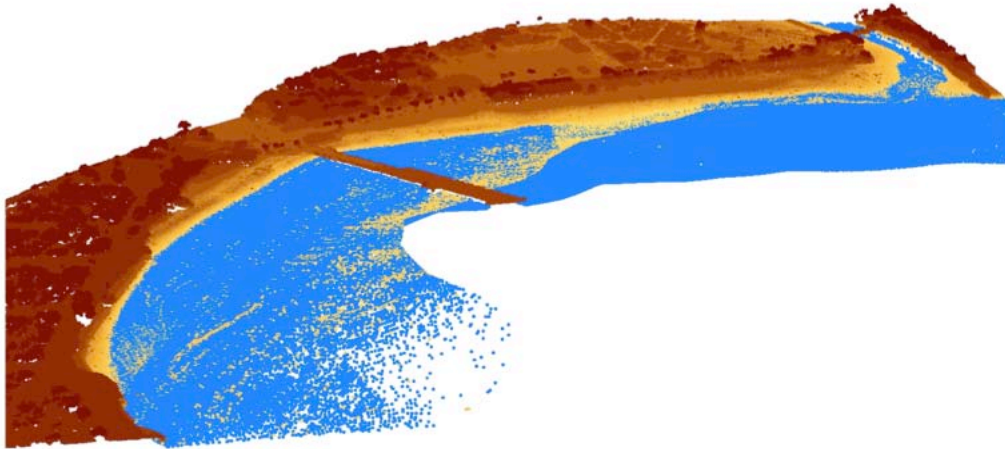


Figure 13d. Main Beach at mean high tide with moderate-high sea level rise scenario (3 ft by 2100).

c. Seabright Beach and Santa Cruz Small Craft Harbor- Prior to harbor construction in 1963-65, Seabright Beach in the summer months was only a narrow sandy strip at the base of the cliffs. In the winter months the waves attacked the cliffs regularly. Average annual cliff erosion rates at that time were a little less than a foot/yr. The construction of the jetties at the harbor trapped sand moving down coast and gradually built a summer beach about 300 feet wide next to San Lorenzo Point, and 600 feet wide adjacent to the west jetty. With the cliffs protected by this wide, nearly permanent beach, the ongoing bluff erosion was essentially halted. Depending upon the rate and magnitude of future sea level rise, however, the beach will gradually narrow and at some point, the waves will again reach the base of the cliffs in the winter and erosion will begin again. When this happens East Cliff Drive will begin to be threatened. The lowest elevation along this stretch of coastline is at the main access path to Seabright Beach at the end of Cypress Avenue. High tides and storm waves do occasionally wash this far inland now carrying logs and other debris. Back beach elevations here are about 14 feet and the lowest elevation along East Cliff here is 24 feet.

- **Santa Cruz Small Craft Harbor-** The harbor facilities and development around the harbor is generally at a low elevation that poses some issues for future sea level rise. The majority of the boat slips at the harbor are on floating docks so are designed to rise and fall with the tides. While there are no problems at present, new pilings being driven are being left several feet higher than the existing piles to accommodate future sea level rise. The boat ramp will gradually get shorter with future sea level rise.

The bulkhead forming the west side of the harbor is lower than that on the east and is overtopped now with the highest tides. The development around the harbor,

however, including the roadways, parking lots and the businesses built on the beach next to the east jetty (the Crow's Nest, for example), and the harbor master's office, are at elevations of 15 to 16 feet and, therefore, are still considerably above any predicted or projected near term sea level rise.

d. High Tide intrusion into the San Lorenzo River and downtown: Because the downtown portion of Santa Cruz is situated on the flood plain of the San Lorenzo River, the entire area from the town clock east to the base of the bluff between Market Street and Branciforte Drive is underlain by sand and gravel deposited by the river over the thousands of years. Water is easily transmitted through these permeable sands and gravels so that the water table or ground water level beneath the city is essentially the same as the river level. During high tides, and when the San Lorenzo River has been dammed by the sand bar that typically forms across the river mouth in mid- to late summer, the impounded water level rises, with still water at times extending upstream as far as the Highway One bridge. From 1895 until 1927 Santa Cruz held a Venetian Water Carnival during the summer with decorated floats along the portion of the backed up river that flows through the city.

One result of this seasonal or temporary impoundment of the river at low flow conditions has been a rise in the water table in the permeable flood plain sands and gravels underlying the city. The summer water surface elevation of the river is typically about 6 feet above sea level and the elevation of much of downtown varies from 10 to 14 feet. As a result, the water table is only 4 to 8 feet below the ground surface, and at times may be within two feet of the surface.

Soil engineers state that the shallow water table affects downtown construction, including the type of foundation and even when foundations can be built. Several feet of gravel fill are often required followed by a layer of reinforced soil or a structural slab. There appears to be a direct connection between the elevation of the water table and the level of the San Lorenzo River.

This elevated water table historically led to ground water seeping into the basements of the downtown buildings, although following the Loma Prieta earthquake and the demolition of many buildings, few basements remain. Some downtown businesses still have sump pumps in their basements. The Boardwalk pumps nearly constantly from their lower levels. City Public Works Department pumps ground water as much as 15 hours a day from beneath the Locust Street parking garage when the river backs up in the summer months.

Ground water rises to collection boxes on Jesse Street and along San Lorenzo Boulevard and must be pumped back into the river regularly. When the lagoon at the river mouth is higher, there is more pumping required and river water is essentially being recycled as it percolates from the river through the permeable sands and gravels to the low lying areas where it is pumped back into the river again.

Due to sediment accumulation in the San Lorenzo River flood control channel, however, many of the gravity outlets that were constructed to carry water from the low lying areas next to the levees back into the river began to be covered over years ago. Recently the city has replaced the original flap gates near the jail that would no longer open with self-opening rubberized valves that are capable of pushing aside the sediment and releasing the pumped water. The City is continuing to replace all flap gates with these new valves on the San Lorenzo River.

As sea level continues to rise, and as summer river discharge declines, the result will be seawater extending farther upstream in the flood control channel more frequently, and rising gradually to higher elevations. This would lead to a rise in the water table beneath downtown. This area of the city has always been vulnerable to an elevated water table but this will become a more significant issue in the future. The higher the water table rises, the greater will be the impact, and the more pumping and other adaptation that will be required.

Recommendation 2. Install a series of ground water monitoring wells (piezometers) in the downtown area to continuously monitor the level of the water table, recording changes seasonally and over time in relation to the river levels.

e. Waste Water Treatment Plant located near Neary Lagoon

The Santa Cruz sewage treatment plant presently serves 135,000 people including 58,000 residents of the city of Santa Cruz as well as people living in the Live Oak, East Cliff and Capitola areas. Septic pumpers dump at the treatment plant as well. In order for gravity flow to be the most effective, the treatment plant was understandably located at the lowest point in the city when it was originally constructed in the 1920's.

The wastewater treatment plant and outfall have gone through approximately \$100,000,000 in upgrades over the past decade or so. The plant was designed to treat up to 17 million gallons/day (mgd), and can pump through 81 mgd to the outfall under high runoff conditions from infiltration and floating of manholes. Ground water and surface water get into the system through cracks in pipes, illegal sump pumps, etc. In the Valentine's Day storm of 2002, water was flowing into the Neary Lagoon site at a rate of 90 mgd, which almost overwhelmed the plant.

The waste water treatment plant faces issues now that will likely become more challenging in the future:

The elevation of the plant and the high ground water levels. The Neary Lagoon treatment plant site was reclaimed from a marshy area by originally placing 4 to 9 feet of fill back in about 1928. This fill was added to in 1948, 1965 and 1974 as the plant expanded. Elevations on site generally range from +9 to +13 feet relative to msl (mean sea level). Some subsidence of the 50 to 70 feet thick underlying weaker marsh sediments has taken place due to the loads of the fill and overlying structures

and will continue in the future. Borings from 1985 indicate that ground water levels are about five feet below the ground surface, or at elevations of +3 to +4 feet (msl), although up to three feet of fluctuation are common.

All of the larger tanks and structures are on piles so are independent of ground water levels. The secondary clarifier tanks are not. These tanks have relief valves in their bottoms so that ground water can be let in under high water table conditions. Otherwise the tanks could be lifted up or float due to hydraulic pressure.

It is not clear if the ground water levels in Neary Lagoon have risen in recent years or how much they will rise in response to a continued sea level rise as water levels across the San Lorenzo River floodplain increase. A rise in ground water levels on the site of the treatment plant may occur, which would exacerbate the existing problems in this low-lying area during the periods of river back up in the summer months. A significant increase in the ground water levels at the site could impact some operations at the facility.

Recommendation 3. Install several ground water monitoring wells in the Neary Lagoon area and continuously monitor the level of the water table including changes seasonally and over time.

B. COASTAL STORM DAMAGE AND CLIFF EROSION

An increase in future coastal storm frequency and/or magnitude would increase cliff retreat rates as well as potential damage to oceanfront property or city infrastructure.

The coastline of northern California, Oregon and Washington have experienced increasingly intense winter storms and greater wave heights over the last 25 years, both of which may be leading to more severe winter erosion (Allan and Komar, 2000). While there is no consensus yet on why storms have been getting stronger, data from wave gauges off the coasts of Oregon and Washington indicate that over the 25 years from 1975 to 2000 that average wave heights increased from about 10 feet to about 13 feet. Over the same period, maximum storm wave heights increased from 36 feet to nearly 50 feet. Greater wave heights when combined with higher sea levels will mean greater erosion at the shoreline.

Storlazzi and Wingfield (2005) of the USGS Pacific Science Center in Santa Cruz recently completed a similar evaluation of changing wave conditions along the central California coast. They analyzed hourly wave data from eight different NOAA buoys deployed off central California between Point Arguello (north of Point Conception) and Cape Mendocino since the early 1980s to determine if and how wave conditions may have changed over the subsequent 22 years. While there is a

considerable amount of data to analyze, they concluded that wave heights are greater during El Niño months. During the 22 years of recorded wave data examined monthly significant wave heights (the average of the highest one-third of the waves and a standard index of wave height) increased about 2 cm/year throughout the offshore area. In other words, average wave heights increased about 44 cm or 1.4 feet over the past 22 years. This period was also characterized by a warm Pacific Decadal Oscillation (PDO) cycle dominated by more frequent El Niño conditions. It is not yet clear what this means over the long-term, but the trend along the entire Pacific coast has been one of increasing wave heights.

Bromirski, et al, (2005) arrive at similar conclusions after conducting a slightly more sophisticated analysis of the same data, namely that the trend off of southern California is for greater extreme wave heights.

- **Cliff Retreat:** While many of the sea cliffs along the city's shoreline are already armored or protected by seawalls or riprap, many are not and will continue to erode. A continuing rise in sea level should move breaking waves progressively closer to the sea cliffs, potentially increasing cliff erosion rates, threatening property, and reducing access to the shoreline. There is a potential for this process to be countered to some degree, however, as larger waves will break in deeper water, or farther offshore.

Recommendation 4. Assess the existing status of cliff protection including an evaluation of the protected and unprotected areas most vulnerable or susceptible to ongoing and future erosion, and build an inventory of the infrastructure or structures that may be threatened.

- **West Cliff Drive-** The coastline extending from Long Marine Laboratory to Cowell's Beach consists primarily of 25 to 30-foot high cliffs that front a flat marine terrace. The cliffs have been eroded into the Santa Cruz Mudstone between the Marine Lab and Almar Avenue, and into the Purisima Formation, a weaker sandstone and siltstone, from Almar to Cowell's.

Observations of historical ground photographs illustrate differences in erosion rates depending upon the local geology. A low rocky shore platform protects the cliffs Observations of historical ground photographs illustrate differences in erosion rates depending upon the local geology. A low rocky shore platform protects the cliffs from Terrace Point at Long Marine Lab to Natural Bridges State Beach. In 1924 the *La Feliz*, a small coastal vessel, went aground on the rocky platform near Terrace Point. The mast was taken off the boat and leaned up against the cliff and used with a block and tackle to salvage the boat's cargo. The mast is still standing 86 years later, indicating no significant erosion has occurred at this location over this time period (**Figure 14a and b**). A quarter of a mile away, however, two of the three arches that

originally existed at Natural Bridges in the late 1800's have collapsed during storms over the past century as the coastline has retreated (**Figure 15 a, b and c**).

Measurements along West Cliff from historical vertical aerial photographs indicate average cliff erosion rates from a few to about 8 inches per year where the cliffs are unprotected. Where erosion does occur, it is usually episodic with large blocks failing instantaneously, rather than gradual losses of several inches each year. However, about 2/3 of this coastline has now been armored with riprap to protect West Cliff Drive and the bike path. From Natural Bridges to Almar Avenue, where the more resistant Santa Cruz Mudstone forms the cliffs, riprap is much less extensive and has been placed primarily in the coves or embayments. Some of this armor consists of concrete slabs dumped decades ago that were never removed in early efforts to halt cliff erosion

From Almar to Cowell's, where the weaker and highly jointed Purisima Formation makes up the cliffs, armoring is more extensive. There is only a single home on the ocean side of West Cliff Drive and it is situated on a small point at elevation 32 feet and protected with riprap and gabion baskets. It is not threatened by wave attack under present conditions.

- **Bethany Curve Bridge**- As discussed above under *Future Hazards of Sea Level Rise*, the bridge over this drainage is the lowest spot along West Cliff Drive and is now the area most susceptible to storm wave overtopping. This area will be more vulnerable in the future with higher sea levels if storm waves become more frequent and larger.

- **Lighthouse Point**- This resistant point is attacked by waves year around but has persisted as a dominant coastal feature for well over a century, which is a key factor in producing the excellent surfing conditions at Steamer Lane. Erosion continues to take place in the Purisima Formation that underlies the point and also in the overlying and weakly consolidated surficial terrace deposits. The history of erosion at Lighthouse Point was analyzed and reported on following losses during the 1983 winter by Rogers Johnson & Associates (1984). Using vertical aerial photographs and historic maps that extend back to 1925, they determined that erosion at Lighthouse Point area averages less than 6 inches/year. Even at an average rate of 6 inches/year, however, in a 20-year time period, ten feet of cliff retreat could take place.



Figure 14a. Wreck of La Feliz in 1924 at Terrace Point



Figure 14b. La Feliz wreck site, 82 years later with ship's mast still leaning against cliff in 2006; note lack of erosion of bedrock platform.



Figure 15a. Natural Bridges in 1900. Courtesy of Special Collections, University Library, UCSC.



Figure 15b. Natural Bridges in 1972. Photo Rogers Johnson.



Figure 15c. Natural Bridges in 2006.

The El Niño winter of 1983 was the most damaging to the Santa Cruz coastline in over 50 years due to a combination of elevated sea levels and a number of large storms arriving at times of high tides in the first three months of the year. Wave

overtopping of the bluff west of the lighthouse removed about 5000 yds³ of terrace deposits, destroying a section of sidewalk and undermining a portion of West Cliff Drive itself. A 100-foot long timber bulkhead built about 1941 and which had deteriorated significantly, was destroyed by wave attack. Erosion of the terrace deposits encroached to within 18 feet of the lighthouse foundation. The solution to this threat was the construction of a protective concrete panel wall on top of the bedrock and then building out fill behind the wall to provide additional protection to the lighthouse from wave overtopping. This wall has fared well in the subsequent 26 years.

There are two caves that extend under Lighthouse Point and the expansion and potential for future collapse of the caves are hazards that will increase as sea level rises and if the wave climate becomes more severe. One cave now extends about 70 feet beneath the west side of the point and has encroached to within approximately 30 feet of the corner of the lighthouse (as of a 4/27/2009 survey). The potential for future collapse will be of increasing concern for public safety.

A second cave is located southeast of the lighthouse. Collapse of portions of the roof of this cave resulted in about 47 feet of horizontal retreat between 1925 and 1963, with an additional ten feet of collapse between 1963 and 1984. A concrete seawall was constructed across the cave mouth in 1980, which reduced erosion for about 25 years until it failed. A survey of this cave in 2000 indicated that it extended 15 to 30 feet beneath the point and to within about 50 feet of the lighthouse. Continued collapse of the cliff in front of the lighthouse has led to relocating the path and the protective barrier inland, although surfers and others commonly climb over the barrier. Public safety for those walking on the paths above the caves and along the cliff edge, as well as the stability of the ground beneath the lighthouse, are both issues that will need to be addressed in the not to distant future.

Recommendation 5. Monitor the depth of penetration of the caves beneath Lighthouse Point relative to the Lighthouse, infrastructure and pathways, as well as the thickness and stability of the overlying materials annually and after major storms.

A large arch existed for years on the east side of Lighthouse Point, which collapsed in the 1888. Subsequent photographs show the gradual lowering of the base of the arch and continued cliff retreat until this area was ultimately armored with riprap (**Figure 16a, b, c**).

Cliffs above Cowell's Beach-West Cliff Drive and the bike path are quite close to and parallel the cliff edge from Lighthouse Point to the Sea and Sand Motel. There is no permanent protective beach until the vicinity of the Sea and Sand such that waves historically attacked the base of these cliffs at most high tides. In the mid- to late-1960's much this area was armored with riprap, which has effectively halted wave erosion. The Sea and Sand is the closest structure to the cliff and are individual units

are 24 feet from the edge at their closest point. A relatively wide beach presently fronts these cliffs most of the year, but at times of high tides and large storms, waves do reach the base of the cliff. Erosion over time formed a large cave beneath the Sea and Sand, which was filled with a concrete soil nail wall about five years ago. Erosion at the base of the cliff has left large joint bounded slabs higher on the cliff, which are



Figure 16a. Arch at Steamer Lane in 1888. Courtesy of Special Collections, University Library, UCSC



Figure 16b. Base of the former arch at Steamer Lane in 1890. Courtesy of Special Collections, University Library, UCSC



Figure 16c. Base of the former arch at Steamer Lane in 1910. Photo courtesy of Frank Perry.



Figure 16d. Base of the former arch at Steamer Lane in 2006. Photo Deepika Shrestha Ross.

unsupported and which occasionally fail by sliding to the beach below. Erosion rates appear to be quite low here although the tree cover on the cliff edge makes measurements of any changes in the location of the edge virtually impossible to document on historical aerial photographs. With continued sea level rise and a more severe storm wave climate, wave attack of the base of the cliffs and therefore cliff undermining and failure can be expected to become a greater hazard.

- **Main/Boardwalk Beach**- The entire 3700 feet of shoreline from the Dream Inn to the river mouth, including the Boardwalk, has been protected for decades with a low concrete seawall. The top of the wall is at an elevation of about 14 feet; so while the beach itself will gradually narrow as sea level rises in the decades ahead, there is no coastal erosion risk in the next 25 years expected because of the presence of the seawall. A significant change in the storm wave climate and in the rate of sea level rise could lead to occasional overtopping.

- **Castle/Seabright Beach**- Prior to the construction of the jetties at the Santa Cruz Small Craft Harbor in 1963, the 2500 feet of Seabright Beach was very narrow, even in the summer months. Waves usually attacked the cliffs during the winter months, and even at many high tides during the summer (**Figure 17**). The beach is backed by bluffs that are 35 to 40 feet in height consisting of Purisima Formation capped by up to 15 feet of weaker terrace deposits. Erosion rates determined from aerial photographs averaged 6 to 18 inches/yr during the decades prior to harbor construction. The jetties trapped littoral drift moving down coast beginning in 1963 and Seabright Beach gradually widened. Over the next 20 years, beach width reached about 300 feet at the west end near San Lorenzo Point and about 600 feet next to the jetty (**Figure 17**). With this wide sandy buffer, wave attack of the cliffs ceased and erosion essentially was halted. Cliff failure at the west end of Seabright Beach did occur during the Loma Prieta earthquake.

As discussed earlier, depending upon the rate and magnitude of future sea level rise, Seabright Beach will gradually narrow over time and the waves will again reach the base of the cliffs in the winter and erosion will begin again. The area that will be impacted first will be the low-lying access-way at the end of Mott and Cypress streets.

C. OCEAN ACIDIFICATION

Ocean acidification describes the decrease in the pH, or the increase in the acidity of the global oceans resulting from the uptake of human generated carbon dioxide from the atmosphere. Less than half of the carbon dioxide produced historically by the burning of oil, gas and coal stays in the atmosphere and about a third currently ends up dissolving into the oceans. This dissolved carbon dioxide forms a weak acid (carbonic acid) in seawater, gradually lowering ocean pH, or making it slightly more acidic. While this process has helped remove very large quantities of carbon dioxide from the atmosphere, reducing the greenhouse effects that would have otherwise been significantly greater, it continues to make the oceans more acidic.

By the first decade of the 21st century, the pH or acidity of the world oceans had increased by about 30% over the “natural” pre-industrial revolution level. As carbon dioxide emissions continue with the burning of additional fossil fuels (coal, oil and

gas now provide about 87% of global energy), additional carbon dioxide will enter the oceans and pH will continue to decrease. Future rates of change will depend upon when and how rapidly the US and the rest of industrialized society chooses to move away from a fossil fuel based economy.

It is believed that this progressive decline in pH or shift towards increased acidity will gradually begin to affect the organisms in the ocean that build their skeletons or shells out of calcium carbonate. These include some of the larger and more visible organisms such as coral, sea urchins, and mollusks, but also many of the plankton with unfamiliar names such as foraminifera, coccolithophores and pteropods. These tiny organisms lie at the base of the food chain and are provide the food supply for the larger plankton such as krill, which are the primary food source for salmon and other fish, as well as sea birds and baleen or filter feeding whales.

Calcium carbonate dissolves in acidic solutions, so the lower the pH, the more difficult it will be for these organisms to either grow new shells or skeletons or maintain their existing health and populations. These changes aren't yet having any direct or measureable effects on the coastal ocean off Santa Cruz. The global ocean trends underway are well documented and considerable research is underway as to how these patterns will affect different types of organisms and how soon. This is a global issue and while it could have some effects on the fauna of the bay at some future time, it is way beyond the reach of our community to significantly affect these global scale processes.

D. CHANGES IN PRECIPITATION, FLOOD POTENTIAL AND WATER AVAILABILITY

Most climate studies and models predict that a warmer ocean will increase evaporation rates that will in turn increase the amount of moisture in the atmosphere. Future precipitation patterns will likely be altered regionally depending upon latitude, topography and storm tracks. One climate model for California developed by Mark Snyder in the Climate Modeling Research Group at UCSC uses a doubling of carbon dioxide in the atmosphere to generate future precipitation changes. For reference, the pre-Industrial Revolution carbon dioxide content in the atmosphere was 270-280 ppm. This had increased about 40% to 388 ppm by 2010.



Figure 17a. Castle Beach showing waves attacking bluffs in 1953, before harbor construction. Courtesy of Special Collections, University Library, UCSC.



Figure 17b. Castle Beach in 2006 with a wide beach protecting the bluffs. Photo Deepika Shrestha Ross.

Is doubling CO_2 a possibility? There are a number of possible scenarios for future carbon dioxide levels that have been presented by the IPCC. If we act immediately to begin to significantly reduce carbon dioxide emissions, the lowest possible level of stabilization, is about 520 ppm, nearly a doubling. But globally, we are still increasing emissions so doubling is unfortunately very unlikely. A business as usual scenario would produce a CO_2 level of 650 ppm by 2100, more than double the pre-Industrial level.

Several different sets of model calculations for the central California coast have been run using a doubling of CO_2 . Two of these show slight decreases in precipitation although these were not statistically significant on a monthly basis (Snyder et al, 2004). A third model compared predicted rainfall in 2080-2099 with that of 1980-1999 and this produced a slight increase in rainfall during the wet season (Snyder and Sloan, 2005). These changes were also not statistically significant. Any model, however, is built on historic data and then some set of assumptions about the future. The natural variability of precipitation is what makes attributing significance to the changes difficult. Other observations of changes in circulation patterns, cloudiness and the water vapor content of the atmosphere would seem to point to wetter winters and more intense storms.

Santa Cruz has a recorded rainfall history that goes back to 1868 (**Figure 18**). The average annual rainfall for the city over this 138-year period is 28.5 inches, and yearly totals range from a low of 10.2 inches in 1924 to a maximum of 61.3 inches in 1941. There are well-documented dry periods with below average rainfall that extended for three or more years in a row: 1868-1871, 1896-1899, 1917-1920, 1928-1934, 1953-1955, 1959-1963, 1975-1977, and 1987-1992. There were also wetter periods with rainfall remaining above average for at least three years in a row: 1893-1895, 1904-1907, 1914-1916, 1936-1938, 1940-1943, 1949-1952, and 1997-2000. Over the past 138 years, however, there is not yet any clear or recognizable trend towards an increase in rainfall. The main trends tend to be higher average rainfalls during warm PDO cycles (1978-2000) and lower average rainfalls during cooler PDO cycles (1945-1978).

Runoff and Flooding. A significant increase in the intensity and /or amount of rainfall during winter months would concentrate runoff and could lead to more frequent or larger flood flows. This would affect flood potential along both the San Lorenzo River and also the major tributaries within the city limits, specifically Branciforte and Carbonera creeks. Santa Cruz' downtown is situated on the floodplain of the San Lorenzo River, and while flood control levees were increased in height following their near overtopping in 1982, there may be a growing potential for future flooding that needs to be considered.

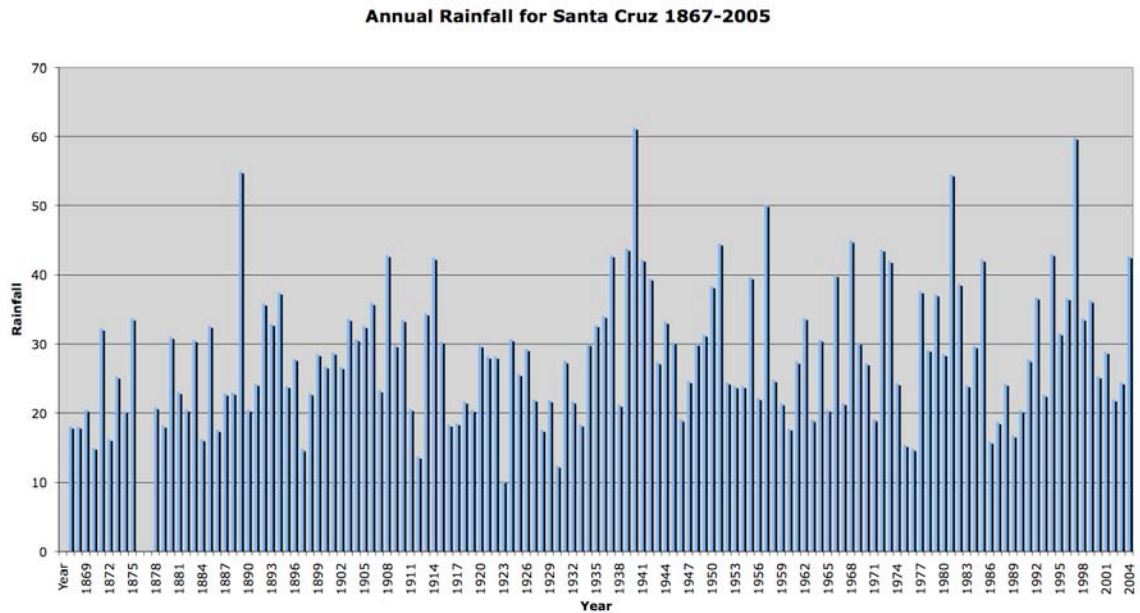


Figure 18. Santa Cruz rainfall history

Like the historic rainfall record, stream flow records for the San Lorenzo River extend back 73 years, and while there are years and periods with higher and lower than normal flows, which tend to follow rainfall patterns, there is no obvious trend of increasing stream flow or more frequent or larger floods. In Figure 19, total annual discharges are plotted in acre-ft/year, and in Figure 20, the peak or highest flow for each year is graphed (**Figures 19 and 20**). Although there is no clear long-term trend, a clear flood hazard already exists for the downtown city center of Santa Cruz.

The lower 2.5 miles of the San Lorenzo River is contained within the levees of the flood control project that extends from the State Highway 1 Bridge to the railroad trestle near the Boardwalk. The levees were built and the natural channel was deepened following the 1955 flooding in Santa Cruz. This was the most recent in a long history of floods that took place in 1862, 1869, 1890, 1895, 1909, 1911, 1931 and 1940. The area now occupied by the central core of the city along Pacific Avenue was not settled or developed in the early history of the city as initial inhabitants recognized that the area was subject to flooding. It wasn't until the time of the California Gold Rush in 1949 that development first encroached onto the flood plain in the area near the present town clock. The street one block north of the clock is named Bulkhead Street and was the former edge of the river. Development and construction continued throughout the remaining decades of the 1800's with occasional flooding followed by reconstruction and more development.

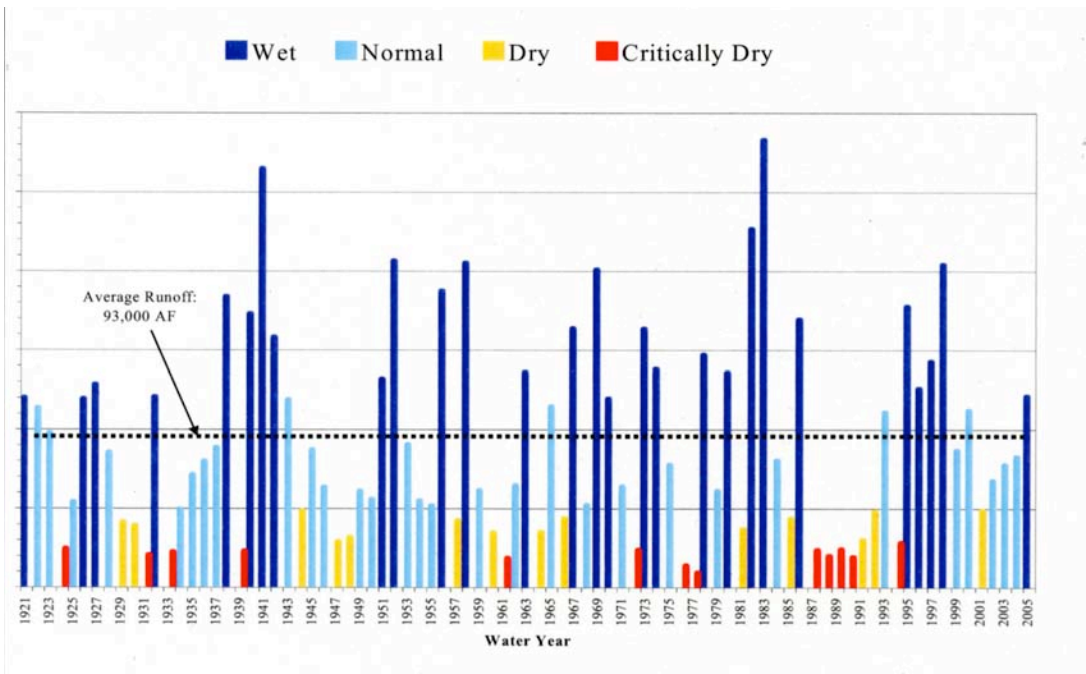


Figure 19. Total annual runoff in the San Lorenzo River (acre-feet)

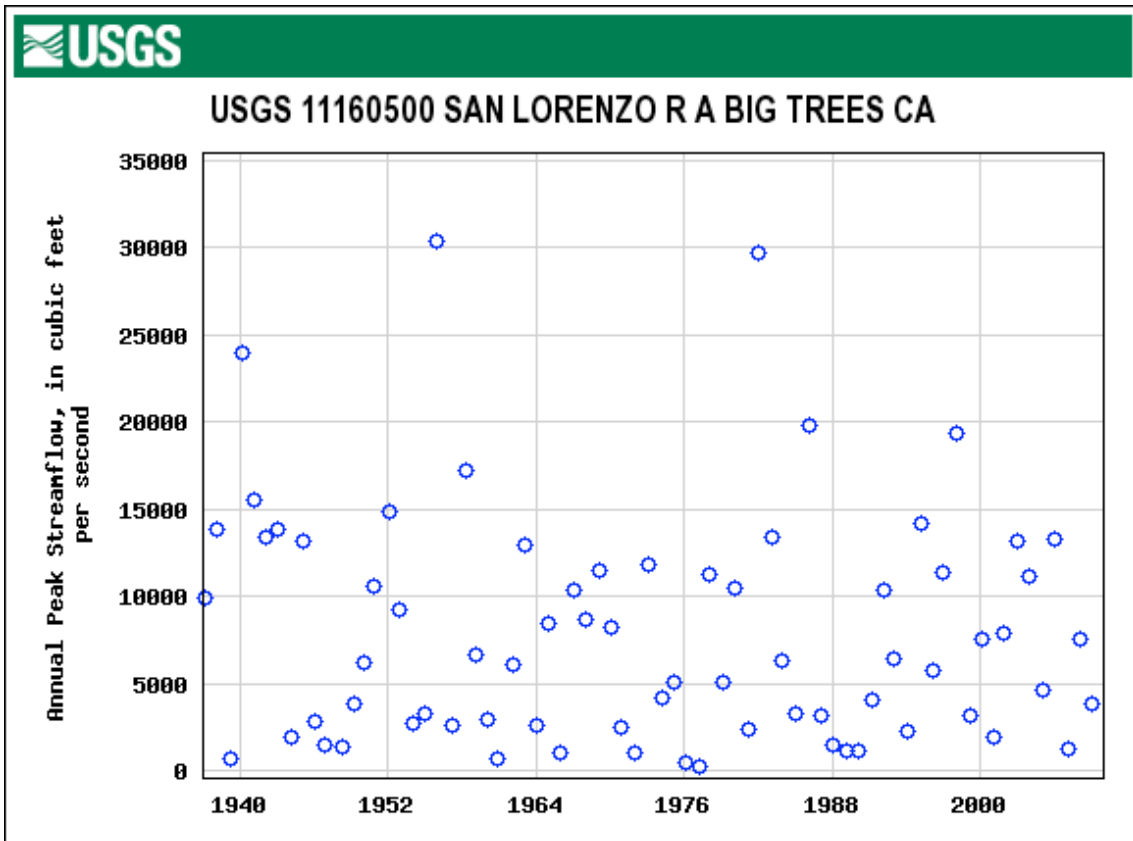


Figure 20. Peak flow by year for the San Lorenzo River at USGS Big Trees gauge in Felton.

Continued heavy rainfall during December of 1955 led to severe flooding throughout the San Lorenzo River watershed. In contrast to very large rivers like the Mississippi, runoff in the upper reaches of the San Lorenzo watershed arrives downtown within a matter of hours. About 20 inches of rain fell in Boulder Creek between the 15th and the 28th of December, with almost half (9 inches) falling on the 22nd. The river sustained the largest flood in the 73-year gauging record with a maximum discharge calculated at 30,400 cubic feet/second (CFS) at the Big Trees Gauge in Felton. The river overflowed its banks from the headwaters to the mouth. Numerous logjams and other channel obstructions diverted the river's course and undercut and scoured out a number of bridges and road fills. The river overtopped its banks in the downtown area and floodwater extended from Ocean Street on the east to the Pacific Garden Mall and beyond on the west (**Figure 21**). Floodwaters reached depths of about three feet along Pacific Avenue (**Figure 22**). Using an inflation index, total damages from the 1955 flood would amount to \$70 million in 2010 dollars.

The 1955 flood stimulated funding for a flood control project that was already in the planning stages by the Army Corps of Engineers to protect downtown Santa Cruz. The design flood was increased, funds were appropriated and construction was completed in 1959. A novel approach was used by the Corps to maximize the amount of land available for redevelopment in the downtown corridor. In addition to the construction of 2.5 miles of levees from the Highway One Bridge to the Southern Pacific trestle, about 770,000 yds³ of sediment was excavated from the existing river channel to increase its slope and capacity.

In July of 1959 the project was completed and deeded to the city of Santa Cruz by the Corps of Engineers. The city agreed to maintain the channel to design specifications and was provided with a maintenance plan and procedure. Total project cost adjusted for inflation was \$47 million, and the Corps estimated annual maintenance costs at the time at \$25,000/yr (\$180,000/yr in today's dollars). The Army Corps departed, leaving the city protected from a projected 150-year flood. Considering the reputation of the Corps at the time, it is not surprising that no one questioned the wisdom of altering the natural channel gradient, the velocities used in the design or the size of the channel. Because the Corps presumably had the most experience in the field of flood control, it was assumed that the project as planned was the best long-term solution. With flood protection assured, the city intensively developed the former flood plain of the now tamed San Lorenzo River over the next decade.

By the early 1970's, however, channel surveys showed that about 400,000 yds³ of sediment had accumulated in the channel, reducing the flood capacity significantly. The accumulated sediment also covered the low-lying gravity outlets that drained the area outside the levees back into the river channel. Thus began a process of flood hazard re-evaluation, maintenance dredging, levee raising and bridge reconstruction that is ongoing today.



Figure 21. Inundation of Santa Cruz during 1955 flood.



Figure 22. 1955 floodwaters flowing down Pacific Avenue.

In January 3, 1982, two major storm fronts sat over the central coast for about 28 hours. Twenty-four hour rainfalls reached as high as 11 – 19 inches in the upper reaches of the San Lorenzo Valley and exceeded the 100-year storm. Prior rainfall had been considerably above the seasonal average such that the rain of early January fell on saturated ground, leading to rapid runoff. The upper reaches of the watershed were hit particularly hard; hundreds of homes were damaged or destroyed by debris flows and floodwaters, and at least 20 lives were lost. Within the city of Santa Cruz the river rose to within 3 to 4 feet of the top of the levees (**Figure 22**), which is the minimum desired free board, and overflowed onto the lowlands of San Lorenzo Park adjacent to the county government center. Large logs and trees, which were swept down the river, piled up at the Highway One and Riverside Avenue bridges, but prompt action by city public works crews using heavy



Figure 22. January 4, 1982 view of the San Lorenzo River looking upstream from the old Riverside Avenue Bridge.

equipment prevented logjams that would have diverted the water (**Figure 23**). Bottom scour led to collapse of one segment of the Soquel Avenue Bridge (**Figure 24**) and cracking of the Riverside Avenue Bridge. Branciforte Creek completely filled its concrete channel (**Figure 25**), but fortunately, peaked several hours before the main San Lorenzo. The flood also peaked at a low tide (Griggs and Paris, 1982). These two coincidences may have saved the entire downtown portion of the city from overtopping and inundation.



Figure 23. 1982 high water at former Riverside Avenue Bridge with crane removing logs and debris so as not to obstruct flow under the low arches of the old bridge.

The Twin Creeks development on Lee Street immediately north of Highway 1 was flooded as Branciforte and Carbonera creeks overflowed. On the south side of the freeway, just off Market Street, a new development, Brookside Glen, had been started with roads and utilities in but no other construction. Creek overflow covered much of the approved development but left the higher middle portion dry.

The 1982 flood was only a 30-year event but made it clear that the level of protection provided by the Corps' flood control project was significantly less than the Standard Project Flood (or ~150 year event). After years of study and analysis involving a city of Santa Cruz river task force, consultants, the state Department of Water Resources and the Corps of Engineers, it was agreed that the sediment infilling of the channel was a major shortcoming of the original design and that modifications were needed to increase the degree of flood protection. The Water Street and Riverside Avenue bridges were ultimately rebuilt to raise the low arches and the levees were raised incrementally, improving the level of protection

The city continues to work with a respected consulting firm (PWA Ltd.) and the Corps of Engineers to reach some understanding and agreement on the level of protection provided by the existing flood control project and what would be required to have the projected certified as meeting the appropriate level of safety. The Corps has recently changed their methodology for flood risk determination, however, and PWA is working on an analysis of uncertainty, and improved flood



Figure 24. High flows in January 1982 in the San Lorenzo River scoured below the depth of the supporting piles leading to collapse of a portion of the Soquel Avenue Bridge. Arrow points to debris line from highest river flows.



Figure 25. Branciforte Creek channel near Water Street on January 3, 1982.

frequency analysis based on additional years of river flow data. The preliminary conclusions that can be drawn at present, based on work still in process, are as follows (PWA Ltd., 2009:

- Most of the present levees appear to meet or exceed a 95% probability of containing a 100-year flood event (a flood with a 1% probability of occurring in any one year).
- The 2,200 foot reach of levee upstream of the Water Street Bridge appears to be deficient and has only an 80% probability of containing a 100-year flood with 3 feet of freeboard. Levee height increase of about 3 feet would be necessary to reach a 95% probability of containment.
- Using additional years of river flow data from the USGS gauging station in Felton the 100-year or 1% flood volume was recently recalculated and determined to be about 12% lower than previous (1990) Corps of Engineers value. (A change in precipitation magnitude and frequency accompanying climate change could change this, however).
- Sea level rise is not expected to significantly affect the certification of the levees in the near future, although it may later. With a 16-inch sea level rise in the bay, peak water levels during a 100-year event are estimated to increase by only 0.3 feet. With a 55-inch rise in sea level (recently projected for 2100 by the Pacific Institute study), peak 100-year flood levels would rise to nearly 1.3 feet, reaching a maximum in the vicinity of the Laurel Street Bridge.

The potential impact of sea level rise on the potential for flooding in Santa Cruz has also been evaluated recently by several state funded studies. If high river flows occur during a high tide, the potential for flooding will clearly increase. A rising sea level will gradually increase the risk of levee overtopping.

A recent *California Climate Adaptation Strategy* (2009) prepared by the California Natural Resources Agency with a panel of science reviewers uses Santa Cruz in a discussion of how sea level rise could alter flood frequency:

“For example, the City of Santa Cruz has a levee system that protects some low-lying parts of the city against a 100-year flood. With a sea level rise of approximately one foot, the anticipated 100-year flood event in Santa Cruz is expected to occur every 10 years, increasing the likelihood of storm-related inundation (Figure 15 from Pacific Institute, 2009).

The Pacific Institute just completed a study for a number of state agencies on *The Impacts of Sea Level Rise on the California Coast* (2009) in which they evaluate flood related risks. In the analysis they use the 100-year flood levels to evaluate the

vulnerability to inundation from future sea level rise. The study notes that people, property and infrastructure are already located in areas vulnerable to flooding from a 100-year event, and many Californians are also already at risk from coastal flooding. Sea level rise will mean more frequent and more damaging floods to those already at risk and will increase the size of coastal floodplains, placing new areas at risk.

A map of Santa Cruz from the Pacific Institute report (**Figure 26**) shows areas in light blue that are currently vulnerable to a 100-year flood event. With a 55-inch (1.4 m) rise in sea level, additional areas (shown in dark blue) will be at risk. Thus the damage attributed to a 55-inch sea-level rise is equal to the area currently vulnerable to a 100-year flood event (but now protected by levees) plus additional inundated areas. This map and others developed for the state's coastal areas are not the result of site-specific studies but are based on the most accurate ground elevations available and were created to quantify risks over large geographic areas. Thus while low-lying areas in downtown Santa Cruz may be presently protected by the levees from a certain magnitude flood event, if their elevation is below the level of present 100-year flood level they would show up in light blue (**Figure 27**). Adding 55 inches (1.4 m) to this elevation will inundate additional areas, those shown in dark blue.

What is unclear in this report and map preparation is the elevation precision or resolution of the base maps used. In other words, if the topographic map resolution is only two feet, there are large potential errors associated with delineating areas prone to flooding with a 55-inch water level increase where slopes are very low and topography is not known down to the precision of a few inches.

Virtually all of the area between the levee and River Street from the Highway 1 intersection to the town clock and then extending across the downtown area to the intersection of Chestnut and Laurel, and then continuing on to Neary Lagoon, all fall within the zone that would be inundated by a 100-year flood combined with a 55 inch rise in sea level. If the levees were to be overtopped by a 100-year or 1% flood, which is presently deemed possible upstream from the Water Street Bridge, even without the 55-inch sea level rise, most of this same area would also be inundated (light blue area in **Figure 26**). As pointed out in the city's Local Hazard Mitigation Plan (2007), the area that would be flooded by a 100-year event includes the Pacific Garden Mall, Center Street, City Hall, the Police Station, Central Fire, the library, Civic Auditorium and many, many other buildings.

On the east side of the flood control channel, most of the low lying area west of Ocean Street between the Soquel Avenue Bridge and San Lorenzo Avenue would be inundated, including the residential area between Barson and Jesse streets. Again, most of this would happen if a 100-year flood overtopped the levees without any rise in sea level. Any significant sea level rise would simply extend the flooding, increasing both the area flooded and the depth of inundation if flooding were to



California Flood Risk: Sea Level Rise Santa Cruz Quadrangle



Figure 26. Santa Cruz projected 100-year flood risk with 55-inch rise in sea level.

occur at high tide.

Clearly these are significant risks that will only increase with a rising sea level and the city needs to continue to work with PWA and the Corps of Engineers to resolve the remaining questions regarding the ability of the levees to contain a 100-yr flood event.

Recommendation 6. Resolve the uncertainties regarding the capacity of the levees along the San Lorenzo River to contain the 100-year flood. There is always the potential for a flood to occur that is larger than the 100 year flood that the levees were initially designed to contain. With the core of the city in its present location it is critical to do all that is feasible to achieve at least 100-year flood protection.

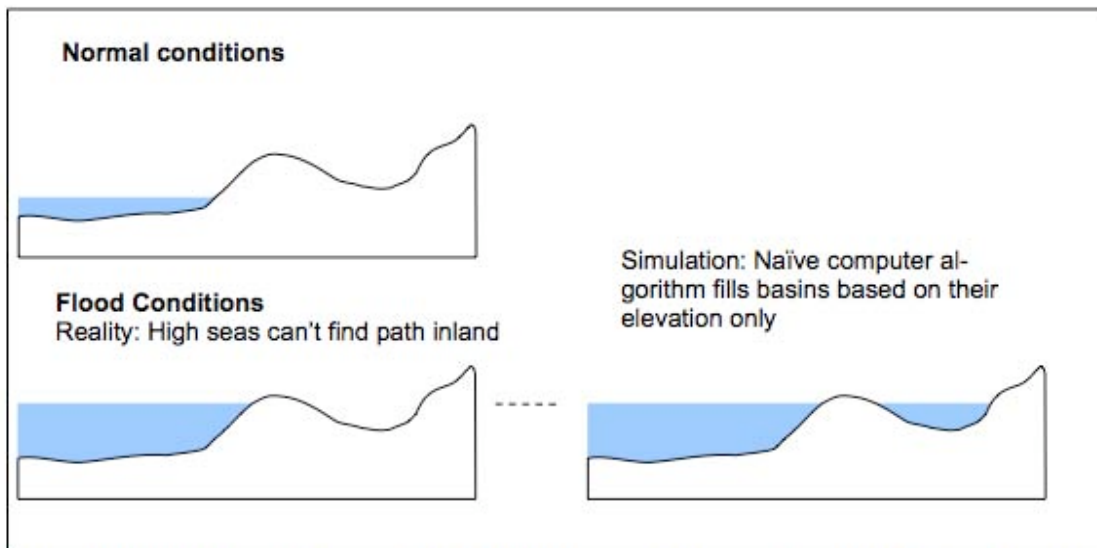


Figure 27. Depiction of limitations of Figure 24 due to computer's inability to accurately map coastal flooding in areas protected by levees in Santa Cruz.

2. Water availability/supply

The City of Santa Cruz Water Department provides water to 90,000 customers spread from Davenport to Live Oak. The city's water system is comprised of four main production elements: 1) the North Coast sources, 2) the San Lorenzo River, 3) Loch Lomond Reservoir, and 4) the Live Oak Wells. The system relies entirely on rainfall, surface runoff, and groundwater infiltration occurring within watersheds located in Santa Cruz County. No water is imported to the region from outside the Santa Cruz area.

The North Coast sources consist of surface diversions from three coastal streams and

a natural spring located approximately six to eight miles northwest of downtown Santa Cruz. These sources are Liddell Spring, Laguna Creek, Reggiardo Creek, and Majors Creek. Use of these sources by the City dates back as far as 1890. The San Lorenzo River is the City's largest source of water supply. The main surface water diversion is located at Tait Street near the City limits just north of Highway 1 and dates back to the 1920s. The Tait Street Diversion is supplemented by two shallow, auxiliary wells located across the river. Another diversion on the San Lorenzo River is the Felton Diversion Station, which is an inflatable dam and intake structure built in 1974, located just downstream from Felton. Water is pumped from this diversion through the Felton Booster Station to Loch Lomond Reservoir. The facility is used to augment storage in the reservoir during dry years when natural inflow from Newell Creek is low. Loch Lomond Reservoir is located near the town of Ben Lomond in the Santa Cruz Mountains. The reservoir was constructed in 1960 and has a maximum capacity of 2,810 million gallons (mg). In addition to the City, the San Lorenzo Valley Water District is entitled to receive a portion of the water stored in Loch Lomond.

There are also three production wells (Live Oak Wells) located in the southeast portion of the City water service area.

Total annual water production over the last twenty years is illustrated in **Figure 28**. These numbers reflect gross water production, which refers to the total amount of raw water diverted at the sources. The figures vary from year to year depending on hydrologic conditions, operations and maintenance, customer demand, and other factors. During this twenty-year period, gross water production ranged from a low of 3.3 billion gallons per year in 1990 to over 4.4 billion gallons per year in 2000. Over the last five years, gross water production has averaged about 4.2 billion gallons/yr. The percentage of total water supply derived from each source between 2000 and 2004 is illustrated in Figure 3-5. Over the last five years, gross production from the North Coast sources has supplied 32 percent of the total annual supply, while the San Lorenzo River (including Tait wells) has supplied about 47 percent. Together, these flowing sources provided nearly 80 percent of the City's yearly water needs. Water supplied from Loch Lomond Reservoir provided 17 percent, and groundwater from the Live Oak Wells supplied the remaining 4 percent.

The changing precipitation patterns described earlier could significantly alter the amount of water available to the city, both surface and groundwater. More intense winter precipitation may result in lower summer base flows reducing the time window during which water can be diverted from streams. Elevated winter flows may also limit diversions because of high sediment loads.

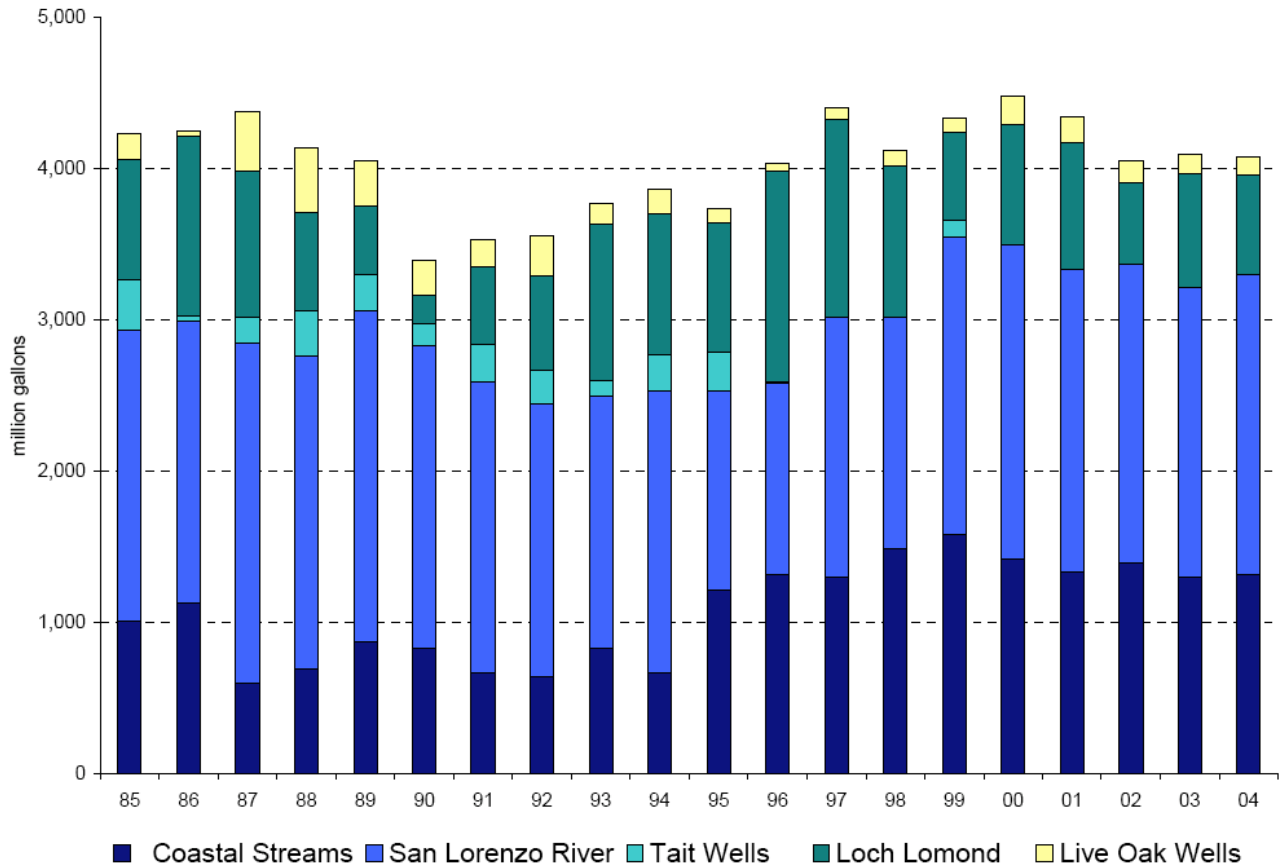


Figure 28. Gross Annual City Water Production, 1985-2004

The city and county of Santa Cruz are somewhat unique in California in being hydrologically self sufficient, with no importation or reliance on external water supplies (with the exception of bottled drinking water). The city has relied on a few historically dependable sources of water for over a century with little significant change in these sources. The amount of water available from these sources changes from year to year as a function of rainfall and runoff, but the total volume available on an annual basis has changed little for many years. Yet demands continue to increase. How the city will cope with the expected changes in water availability is a significant challenge.

The City Water Department has recently (2009) prepared a Water Shortage Contingency Plan, which is a very thorough assessment of water supply and demand and also develops a demand reduction program consisting of different Stages of severity and planned responses.

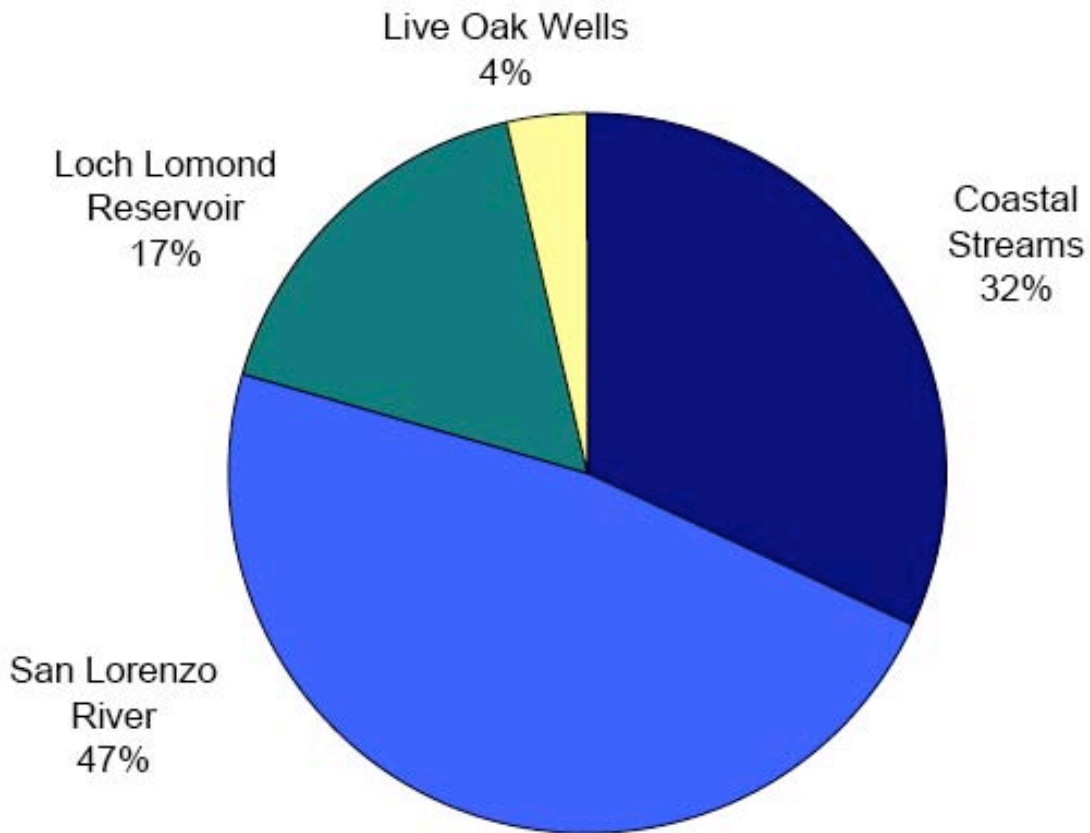


Figure 29. Percent of total City water supply by source, 2000-2004

Storage of winter runoff is the primary mechanism through which the city can continue to provide water during summer and low surface flow conditions. Loch Lomond serves as the city's primary storage reservoir and has provided an average of 17% of the supply over the past five year. The reservoir has a storage capacity of about 2.8 billion gallons. In wet or normal years the reservoir naturally fills to capacity with runoff from Newell Creek, usually by February or March, or water can be pumped up from the diversion dam in Felton. The problems come in dry years or with a drought and several dry years in a row, which is expected to become more common as the climate continues to warm. The challenge is how to store more of the winter runoff, and it would take a very large amount of storage to significantly increase the city's storage capacity. A dam and reservoir site were studied on Zayante Creek decades ago and much of the land was purchased, but for a number of reasons, seismic and economic factors in particular, those plans were terminated.

It seems unlikely at this point that a large dam and reservoir would be constructed anywhere in the county.

3. Sea Water Intrusion. Because most of the City's potable water is supplied from surface sources, there is generally not much concern for seawater intrusion within Santa Cruz itself. The City does operate a small number of wells close to the lower San Lorenzo and in Soquel that could be affected by seawater intrusion through a combination of sea level rise, diminished surface flows and lowered ground water levels.

In addition, the city is bounded on the south by the Soquel Creek Water District, and pumping patterns within the City limits can influence how the adjacent district distributes its use of ground water. Seawater intrusion is of greatest concern where overdraft is severe, and where permeable formations outcrop below sea level, for example in the agricultural areas of southern Santa Cruz County. Nevertheless, it is worth examining the potential influence in the future of changing precipitation and river flows, and the distribution of pumping in near-coastal areas, within city limits. Even if sea water intrusion is not an anticipated problem, there may be greater impacts on flows of the San Lorenzo River as a result of changes in both pumping and precipitation patterns.

D. CHANGING TEMPERATURES

Changing temperatures could have numerous impacts on the City. Climate change could result in a steady average increase in overall temperature, but also in more extreme events, such as heat waves and frosts.

In terms of both rising average temperatures and the possibility of extended periods of high heat during crucial growing periods, the City shares part of its water supply, originating along the north coast, with coastal growers. If coastal growers increase their irrigation intensity as a result of increasing temperatures, the City would have less water for its own use. This scenario was nearly reached in July, 2009, during the third year of the recent drought.

In terms of urban water demand, high temperatures occurring during May and June, when residential gardens are planted and are sprouting, produce increases in water demand. This is a valued amenity to residents who own or rent homes. Currently the City has sufficient normal-year water supplies to provide water during May/June heat waves. However, the combination of heat waves and extended (two or more year) droughts raise a more generalized water sufficiency problem. The City is addressing this issue through a combination of use-curtailment planning and drought supply augmentation via a planned water desalination facility. The Water Department also recently completed a comprehensive Water Shortage Contingency Plan (January 2009).

E. WILD FIRES

Santa Cruz coastal fog contributes to generally greater moisture in the fire-prone vegetation surrounding the city compared to similar wild land-urban interfaces in southern California. As a result, Santa Cruz fires typically burn slower and longer than southern California fires. In anticipation of reduced coastal fog patterns, city and county fire response units could adapt their planning, training, and inventory of supplies to deal with hotter, faster-burning wildfire events.

Agencies can also review their regional cooperative support agreements in light of increased wild land fire risks and review and update plans and data for the regions that are managed by Cal Fire.

The profile and risk of urban fires, or structure fires, is not anticipated to change as a result of climate change in Santa Cruz.

Recommendation 7. Work collaboratively to reduce boundary-region wildfire risk through forest and grassland management techniques.

F. NATURAL RESOURCES IMPACTS

Climate change-related events can lead to a number of problems concerning water supply. Sea level rise could introduce ocean water into the freshwater aquifers currently tapped by the Beltz Wells. The wells may have to be relocated further inland to avoid saltwater intrusion. The City can take action now by developing and reviewing models of aquifer impacts during sea level rise; coordinating with neighboring Soquel Creek Water District, which also uses the aquifer; and reviewing and updating its well relocation plans based on what is known about sea level rise.

Increased fire risk and fire intensity could cause clogging of intakes in the north-coast-river water supplies used by the City. Three streams, Liddell, Laguna, and Majors, provide roughly 25% of the City's water and have been in service since the 1880s. Following a major fire in the 1910s, Laguna Creek was not usable as a city water supply due to silting and clogging of intakes.

Recommendation 8. Prepare for increased north-coast stream intake clogging risks by establishing procedures and preparing for any notifications, approvals, and permits that may be required by agencies responsible for endangered species, environmental restoration types of issues following a clogging event.

Another water-related natural resource impact has to do with potential increases in

the intensity of storms and subsequent sediment runoff in the San Lorenzo River. The San Lorenzo River is the City's primary source of drinking water. The Graham Hill Treatment Plant is able to treat water with up to 25 NTU of turbidity, a measure of the cloudiness of water due to siltation. Major storms mobilize sediment that far exceeds 25 NTU. If storm intensity and frequency increase, the length of time the City can draw water from the San Lorenzo River will decline. This situation will call for adaptations that either enable the city to draw siltier water into its system and thoroughly treat it, or draw and store more raw water when it is available in anticipation of the longer periods when water is not available. Expanded storage for treated water is also a possibility. The 39 million gallon Bay Street Reservoir is in the process of being replaced with two 6 million gallons tanks.

Water Transmission System

Loch Lomond Reservoir, the City's primary water supply in the event of a drought, faces numerous climate-change-related challenges including maintenance of a 9-mile long pipeline that delivers water to the City from the reservoir along with other transmission pipes throughout the system. Climate change could increase the risk of wild fires along transmission lines, which, combined with subsequent flooding, could destabilize the steep slopes along the transmission lines. For example, slope failures during the heavy rains of 1982 damaged the pipeline leading to shut down of flow. Additionally, supporting roadways used to transport maintenance and repair equipment may be unstable and unusable. This scenario is roughly equivalent to what the Water Department could face following a major earthquake. A similar scenario could occur due to climate change, emphasizing the importance of advance preparation of transmission lines for multiple types of emergencies.

Recommendation 9. Prepare for increased risk to water transmission pipelines, evaluating whether sufficient pipe replacement and repair supplies are in inventory or readily available along with the ability to repair or relocate lines damaged by weakened or collapsing hillsides.

Increased fire potential in the Loch Lomond watershed means a greater chance that post-fire rains could introduce a much more rapid influx of sediment, reducing the storage capacity of the reservoir.

Recommendation 10. Reduce the risk of fire in the Loch Lomond watershed through fire prevention activities ranging from increased security patrols that curtail the use of personal fires to public information campaigns to forest management programs that reduce the likelihood of a major fire.

Another climate-change related risk to the reservoir concerns the increasing rate of evaporation caused by increased air temperatures and higher insolation (influx of sunlight) due to a decline in coastal fog. The Reservoir currently loses 3 to 4 inches

of water per year to evaporation, as much as 20 million gallons of water. Increased evaporation could affect the amount of water available to the City to respond to extended droughts. The City could adapt to increasing evaporation at Loch Lomond Reservoir by increasing its reservoir filling operations to make up for lost water, or by pursuing other drought water options, such as the proposed desalination facility.

G. ECONOMIC DEVELOPMENTS AND HOUSING

Climate change preparation and adaptation will impact the economic base of the City. Including tourism, farming, and technology. The shape of tourism may evolve from the traditional weekend family to climate refugees escaping to the coast from warmer inland locations. Protection or relocation of basic infrastructure to support these changes is critical. Crop types or planting seasons may change as well. The City should consider how to meet these new challenges and be flexible in adapting economic policies and outreach that support a changing economic climate.

Economic Development and Redevelopment

Established after the 1955 floods, the Redevelopment Agency has historically focused on downtown redevelopment. The Agency applies for state and federal disaster assistance and other grants, and partners with the City and with private developers and property owners. Agency activities must be shown to be of benefit to the redevelopment area.

Recommendation 11. The potential impacts of climate change should be considered in each Redevelopment Agency project or program undertaken.

1. Do not encourage or partner in development projects that are located in regions that are at risk of climate-change-related flooding or rising water tables.
2. Identify long-range economic opportunities and promote siting in climate resilient locations.
3. Include climate-change-related criteria when evaluating and supporting affordable housing development. This would include using lighter shades of paint that reflect sunlight, reducing interior heating; flood resilient design; and selection of locations that are not subject to flooding or salt water intrusion.
4. Participate in City efforts to establish accurate FEMA mapping of flood risks as a result of climate change. Use this mapping information to inform decisions about project selection and support.
5. On a case-by-case basis, the Redevelopment Agency may be able to help with the relocation of critical city infrastructure (e.g., wastewater treatment plant) that is

threatened by flooding or a rise in the water table due to climate change. The Agency must make a compelling case that assistance in each case is strongly beneficial to the city. The Agency can begin developing the outlines of these cases in advance of the decision to relocate infrastructure.

Regional Impacts

Among the regional impacts one could anticipate from climate change are an influx of out-of-town guests greater than usual during periods of extreme heat in the greater San Francisco Bay Area. This would both increase economic activity in the City and stress its infrastructure. Because the ocean will exert a cooling influence on air temperatures, Santa Cruz should remain a desirable location to live as average temperatures rise. This could contribute to the historic upward pressure on housing costs in the City.

RISK ASSESSMENT

Adaptation to climate change is fundamentally a risk management strategy, or an insurance policy against an uncertain future. Risk is a combination of the *likelihood* of any of the previously described climate related events occurring in the future, and the magnitude of the potential *consequences*. Some processes or events, several years of drought, for example, have occurred often in the past and have a very high probability of occurring in the future, probably more frequently. The consequences of a prolonged drought can be very significant. The product of the probability and consequences of drought and the associated water shortages, therefore, produce a very high risk rating, over both the short and long-term (**Figure 30a and 30b**).

The consequences of any particular event might be economic, social, or environmental. In this section we include a general qualitative assessment of risks but don't attempt to assess specific types of consequences. Additionally, risks for each of the climate-related events facing the city of Santa Cruz in the future are evaluated for both a *short to intermediate time frame* (2010-2050), and also an *intermediate to long-term time frame* (2050-2100). We have chosen to use three different levels of **Magnitude**: Low, Moderate and High, and four different levels of **Probability** or **Likelihood of Occurrence**: Low, Moderate, High and Very High.

Processes such as floods and droughts reflect *climate variations* or *fluctuations*. For these types of events we have good records, simply because the city has experienced these types of events many times throughout its history. We therefore have a high degree of certainty that both floods and droughts will occur in the future. The uncertainty lies in how much more frequent and how much more severe these events will be in the future as a result of *changing climate*.

		Probability / Likelihood of Occurrence			
		Low	Moderate	High	Very High
Magnitude of Consequence	Low			Heat Wave	
	Moderate	Shoreline Inundation		Coastal Cliff Erosion	
	High	Wildfires	Downtown Flooding	Water Table Rise Downtown	Water Shortages

Risk = Probability x Consequence

Figure 30a. Short to Intermediate Term Risk Ranking 2010 – 2050

		Probability / Likelihood of Occurrence			
		Low	Moderate	High	Very High
Magnitude of Consequence	Low				Heat Wave
	Moderate		Shoreline Inundation		Coastal Cliff Erosion
	High		Wildfires	Downtown Flooding	Water Shortages Water Table Rise Downtown

Risk = Probability x Consequence

Figure 30b. Intermediate to Long-Term Risk Ranking 2050 – 2100

There are other events related to climate change, those related to sea level rise for example (inundation of low lying coastal areas, a rise in the water table beneath the downtown area), where the future unknowns are higher, simply because of the lack of certainty in future greenhouse gas emissions and how these will influence future climate and sea level rise. Despite the uncertainties, we can make some judgment as to the relative level of risk that each of these pose to the city based on some range of future projections. Based on the trends of the past century and the various climate models that have been developed, the risks from each of these climate-related events facing the city of Santa Cruz will almost certainly increase in the future (**Figure 30a and b**).

Over the next 40 years (between 2010 and 2050), we believe that the highest risks to the city of Santa Cruz will come from:

- a. Water shortages due the combination of increasing temperatures and changes in precipitation patterns during the year with more concentrated winter rainfall. This has both a high probability of occurrence and also significant consequences.
- b. A rise in the water table beneath the downtown portion of the city is already an issue. As sea level continues to rise, the present problems will be exacerbated. The consequence of a continuing water table rise on downtown buildings and infrastructure, including the sewage treatment plant, and the need to dewater certain areas at present, as well as the likelihood of this taking place in the future, is high in the immediate future but the risk is very likely to increase substantially over the long-term.

Over the long-term, 2050-2100, in addition to water shortages and a rise in the water table, we believe that other climate change related events would increase to *high* and *very high* levels of risk within the city:

- c. The potential for overtopping of the levees and flooding of downtown has a moderate probability of occurring with the present levee conditions but has a very high consequence if it were to happen. If winter precipitation intensity and magnitude increase in the longer-term future, although it is not clear from the models that have been run to date that this will occur, the probability of levee overtopping will increase, raising the risk of flooding.
- d. Coastal cliff erosion takes place now, although most of the areas of highest vulnerability have already been armored with riprap or seawalls. Probability of this continuing is therefore high, although consequences are deemed only moderate because most critical areas have been protected and there is not a lot of high value infrastructure that is presently exposed. In the long-term, however, with a rising sea level and increased winter wave attack, we believe that this risk will increase to a higher level.
- e. Shoreline inundation would affect only a limited area of development along

the city shoreline, even at the maximum projected sea level values for 2050-2100. The harbor may have the highest risk, particularly along its west side. Flooding of the main city beaches, Cowell's, Boardwalk and Seabright beaches would become an increasing issue as sea level reaches two or three feet above the present. As these beaches gradually narrow, tourism and recreation will gradually be affected. The probability of this occurring in the intermediate to long-term future is moderate and the consequences are deemed to be moderate.

IMPEDIMENTS TO CLIMATE CHANGE ADAPTATION

Despite the substantial economic assets of the our nation, our state, our community, our adaptive capacity to respond to new stresses associated with climate change is limited. As a starting point, it can be argued that our societies are not even well adapted to the *existing* climate, especially to well-understood natural hazards (earthquakes, hurricanes, floods, drought) that continue to result in human disasters. Numerous reports and academic research studies describe longstanding impediments to natural hazards mitigation, and these challenges will continue to limit our capacity to adapt to climate change—especially when it involves the intensification of natural hazards (NAS-NRC, 2010).

Adaptation requires both actions to address chronic, gradual, long-term changes such as sea level rise, and actions to address natural hazards that may become more intense or frequent (droughts or floods). Addressing gradual changes is challenging because the eventual extent of such changes is difficult to recognize and measure; plans beyond 20 years are usually met with skepticism; and costs for initial investments may be deemed unaffordable even when they would be cost-effective in the long-term.

For several decades, *adaptation* to climate change has been neglected in the United States, perhaps because it was perceived as secondary in importance to *mitigation* of climate change (e.g. through greenhouse gas emission reduction), or perhaps more importantly, because it would actually take attention away from mitigation by implying that the country can simply adapt to future changes. In addition, the topic of climate change and the discussion of options for responding have become much more highly politicized in the United States than in some other parts of the world. Arguments in the media over whether climate change is “real” and to what degree it is a problem generated by human activity have confused people about whether action is needed and whether their actions can make any difference. Further, there are frequent suggestions in the media that responding to climate change is “too expensive” or that the options available to limit emissions and adapt to impacts will have a negative impact on the U.S. economy. We believe that the long-term risks and costs of not responding are far greater than the short-term costs of reducing our

dependence on fossil fuels and transitioning to renewable energy sources; in fact, California has much to gain economically from this transition.

On a local level, there are those who see climate change only as a rise in temperature of a few degrees, which they feel is of no concern; those who say that their hands are tied and that they feel powerless to have any impact so why bother; those who are simply tired of hearing about the problems and are suffering issue fatigue; those who have difficulty dealing with probabilities, and who want perfect information and complete agreement before they are willing to believe in the problem and make change (Moser, 2009).

Adaptations to long-term problems involve long-term investments and also bring considerations of intergenerational equity and other social and economic factors into play that significantly affect the calculation of costs and benefits. The influences of climate change extend well beyond the election cycle of the typical public official in the United States. Long-term adaptations must, therefore, hold some promise of short-term reward if they are to be attractive to elected decision-makers.

PRINCIPLES FOR ADAPTATION

Coastal adaptation strategies fall into two major categories (Climate Action Team, 2009):

1. Strategies for existing development, including existing infrastructure and other resources located in potentially vulnerable areas. Strategies for addressing climate change impacts include rolling easements, relocation incentives from high risk areas, government purchase of vulnerable property, seawalls to protect critical infrastructure, planned retreat, and rebuilding restrictions for vulnerable structures following climate-related disasters.
2. Strategies for new development, including mandatory setbacks to restrict development in vulnerable areas, required warning notices to developers and buyers on potential impacts of future climate change, smart growth and clustered development in low-risk areas, designing for climate resiliency, and the development of expendable or movable structures in high-risk areas.

ADAPTIVE CAPACITY

For each risk identified for the city, there is typically a set of possible adaptation measures or strategies that could be implemented to reduce the future exposure from the specific risk. For some risks, Santa Cruz can significantly reduce its vulnerabilities by taking some relatively direct actions; in other words, we have a *high adaptive capacity*. One good example would be the adequacy of future water supplies. Two high priority actions or strategies would be 1] increased water

conservation efforts during drought periods (and such a plan has been already been completed by the Water Department), and 2] the construction of a desalination plant. Again, planning has been underway for such a facility for some time and significant progress has been made. Although there are environmental issues to resolve, technologies are mature, costs are reasonably well known, and such an approach is a fairly straightforward strategy or solution. So we can adapt.

For other risks, there is very little that can be done to ease or reduce the future impacts, or in other words, we have a *low adaptive capacity*. Perhaps the best example is the challenge the city will face in dealing with a significant future rise in the ground water table beneath the downtown area. This portion of Santa Cruz was built on the flood plain deposits of the San Lorenzo River, which consist primarily of sands and gravels that have a high permeability. As a result the water table is believed to closely reflect the water level in the adjacent river. As sea level continues to rise, the water level in the river will rise at high tides and the ground water table beneath the city will experience the same rise. This happens now and has for some years but will worsen in the future. There does not appear to be a practical solution or adaptive response such that the city has a low adaptive capacity. In **Figures 31A and 31B**, the adaptive capacities have been listed for both the Short-Intermediate Term (**31A**), and Intermediate to Long-term (**31B**).

PROGRESS ON ADAPTATION ACTIONS AT THE STATE LEVEL

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

“Given the extent of the threats predicted by current climate models, sea level projections, and the considerable value of California’s coastal lands, resources and developments, coastal planning in California must address adaptation to a variety of potential significant outcomes of climate change. Preparing California’s coastal infrastructure, industries and ecosystems for the impacts of climate changes will be an expensive endeavor. Decision-makers will need to make short and long-term decisions to address future impacts that will include maintaining existing natural and human developments by protecting, rehabilitating, retrofitting, supplementing, and constructing these systems.”

“While the exact future of the coast is uncertain, one thing is clear: we’re going to have to change the way we think about managing our natural assets and human development. Existing laws (such as the California Coastal Act) provide state and local governments with tools for addressing the effects of climate change, but also impose some significant limitations. Laws written in and designed for the 20th century will need to be updated to reflect new ideas about climate change in the 21st century.”

Hazard	Risk	Adaptive Capacity of the City of Santa Cruz
Water Shortages	Very High	High
Ground Water Rise	Very High	Low
Coastal Erosion	High	Moderate
River Flooding	Medium	Moderate
Heat Waves	Medium	Low
Wildfires	Low	Moderate
Coastal Inundation	Low	Moderate

Figure 31A. Adaptive Capacity to Climate Change Impacts Over Short – Intermediate Term (2010 – 2050)

The draft report lists six overall strategies, which provide some state agency perspective on future adaptation planning for the state’s coastline:

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

Hazard	Risk	Adaptive Capacity of the City of Santa Cruz
Water Shortages	Very High	High
Downtown Water Table Rise	Very High	Low
Downtown River Flooding	Very High	Low
Coastal Cliff Erosion	Very High	Moderate
Shoreline Inundation	Medium	Low
Wildfires	Medium	Moderate
Heat Waves	Medium	Low

Figure 31B. Adaptive Capacity to Climate Change Impacts Over Intermediate to Long-Term (2050 – 2100)

Strategy 5 is specific to the state’s interest in local community adaptation planning efforts and lists a set of eight general strategies that are recommended for consideration by local governments when updating local plans:

- i. **Setbacks** – Mandatory construction setbacks can be imposed to prohibit construction and significant redevelopment in areas that will likely be impacted by sea level rise within the life of the structure.
- ii. **Additional Buffer Areas** – Additional buffer areas can be established in some places to protect important cultural and natural resource assets.
- iii. **Clustered Coastal Development** – Coastal development can be concentrated in areas of low vulnerability and may reduce carbon emissions from transportation.
- iv. **Rebuilding Restrictions** – Rebuilding can be restricted when structures are damaged by sea-level rise and coastal storms.
- v. **New Development Techniques** – Building codes can be amended to require that coastal development incorporate features that are resilient to sea level rise (e.g., require that development begin on the second floor).
- vi. **Relocation Incentives** – Federal, state and local funding or tax incentives to relocate out of hazard areas.
- vii. **Rolling Easements** – Policies and funding to facilitate easements to a) relocate developments further inland, b) remove development as hazards encroach into developed areas, or c) facilitate landward movement of coastal ecosystems subject to dislocation by sea-level rise and other climate change impacts.
- viii. **Engineering Solutions** – New engineering approaches will need to be applied to ports,

marinas and other infrastructure that must be located on the shoreline to maintain their function as the sea level rises.

CLIMATE CHANGE ADAPTATION STRATEGIES FOR SANTA CRUZ

Using the recently completed National Research Council Report (*Adapting to the Impacts of Climate Change*, 2010), the newly released state Resources Agency Report (2009 *California Climate Adaptation Strategy*), as well as the input from the Santa Cruz city agency staff interviewed, and our own personal familiarity and experience with the climate change issues facing the city, we have developed a set of possible adaptation actions or strategies for each of the vulnerabilities and impacts that have been recognized and evaluated. A table has been developed (**Figure 32**) to summarize each of these, although each impact and each possible adaptation action are discussed below to provide additional explanations. These actions or strategies include a broad range of approaches including: future planning for problem or hazard avoidance, engineering (retrofitting, rebuilding, construction, and protection), and retreat or relocation.

CLIMATE CHANGE PROCESS	IMPACT	POSSIBLE ADAPTATION ACTION
Continuing and accelerated sea level rise	Gradual inundation of low lying developed shoreline areas	Design and site all future City projects and infrastructure to account for sea level rise projections based on projected life span of project.
		Develop retreat or retrofit plans for existing infrastructure subject to future inundation.
		Develop a retrofit or protection plan for raising west side of harbor to mitigate for possible overtopping.
		Establish mandatory rolling setbacks for any future development or significant redevelopment in areas likely to be impacted by sea level rise within the anticipated life of the structure.
		Develop a retrofit plan to raise the top of seawall along Beach Street to prevent future overtopping.
		Restrict rebuilding when structures are damaged by sea level rise and coastal storms.
		Develop policies and identify funding or tax incentives to relocate out of areas subject to future sea level rise.

	Gradual inundation of beaches where back edge of beach is fixed with a structure	No practical adaptation measure.
	Rise in groundwater table beneath waste water facility	Consider all possible engineering solutions (cut-off walls, grouting or other barriers) to separate sewage treatment plant site from local ground water table.
		Develop long-term contingency plan for complete relocation of plant.
	Rise in groundwater table beneath downtown area of city	Abandon remaining basements in downtown area.
		Prepare to increase and expand existing groundwater pumping activities.
Plan on how to deal with subsurface utilities or infrastructure that may be impacted by a rising water table.		
Increased frequency and intensity of coastal storms	Increased frequency and magnitude of wave run-up and storm surge	Develop plans for dealing with occasional overtopping or inundation of existing coastal structures (vulnerable areas along West Cliff Drive, Beach Street and Boardwalk, sewage pumping station)
	Increase in cliff erosion rates	Evaluate unprotected West Cliff areas subject to future erosion and develop plans and timeline for either armor placement, or retreat and relocation of existing structures or infrastructure.
		Evaluate presently armored areas to determine whether additional armor or retreat is most practical long-term approach. Relocate pathway at Lighthouse Point away from cliff edge and underlying caves.
Changing patterns of seasonality of	Increased frequency and magnitude of	Review and update 100-year flood map.

precipitation	winter flooding in response to more concentrated winter rainfall	Review and update 100-year flood map.
		Complete re-assessment of flood potential for downtown portion of city and develop economic and engineering feasibility plans for raising levees.
		Consider reclaiming area adjacent to river channel for increasing capacity of flood control project and other compatible uses (e.g. San Lorenzo Park example)
	Reduced water availability in summer months	Consider and explore regional water supply expectations
		Establish open purchase orders with water suppliers who can be quickly accessed (e.g., nearby well water, other surface users).
		Include climate change impacts for proposed construction plans for desalination (e.g., coastal inundation, power outage)
		Review Bay Street Reservoir replacement planning in terms of climate change impacts; explore feasibility of volume expansion if necessary
Higher temperatures and lower rainfall	Increased wildfire intensity and frequency	Include climate change impacts in Emergency Operations Center preparedness
		Review mutual aid agreements in terms of multiple-fire risk
		Accelerate urban-wild land interface fuel management programs, including fuel reduction and fuel break programs
		Inventory at-risk structures and implement enhanced emergency warning system
		Develop local response plan for multiple simultaneous wild land-urban interface fires

	More intense heat waves (hotter, longer)	Develop strategy for contacting home-bound or disabled residents and moving them to air-conditioned shelters as needed
		Review plans to prepare for potential influx of 1- day to 1-week visitors to city from hotter inland regions
		Update plans for heat-wave-caused power outages

Figure 32. Adaptation actions for each climate change impact facing the city of Santa Cruz.

Continuing and Accelerated Sea Level Rise

Sea level rise is the process that has generated some of the most visible effects in Santa Cruz historically, it is the climate change impact that will likely have some of the largest effects in the future. Each of the probable future sea level rise impacts discussed have a level of uncertainty simply because we don't know with confidence 1) how fast sea level may rise globally in the future, 2] what the actual trend of local sea level rise is along the Santa Cruz coastline (although it seems to be reasonably well constrained between the rates at Monterey and San Francisco), and 3] how high sea level may ultimately get before natural climate cycles may begin to reverse the warming we have been experiencing.

Figure 6 presents the most recent range of sea level rise values projected for California that state agencies are now using. Based on low, medium-high, or high future greenhouse gas emissions, projections for 2050 are similar for all cases, about 1.4 feet (0.44 m). By 2100, however, the projections diverge and range from 3.3 ft to 4.8 ft. In order to help resolve these uncertainties or at least use a common approach, a National Academy of Sciences study has been initiated to determine the best values for sea level rise for the entire West Coast, including related factors such as changes in storm intensity and frequency for the years 2030, 2050 and 2100. When the study is completed, it will at least allow for consistent estimates for sea-level rise along the West Coast. As satellite data for sea level rise continue to be recorded, these values will no doubt be regularly updated.

Future impact of sea level rise is dependent both on the magnitude of the increase

but also the topography of the particular shoreline area. In July 2010, the California Ocean Protection Council authorized \$2.75 million for NOAA to collect and process aerial LiDAR elevation data and imagery along the coast of California. This project will produce a high-resolution topographical map of California's entire coast. Elevation data is essential for more accurate predictions of the effects of sea level rise on the coast, and this statewide dataset would serve as a permanent record of California's current coastal elevations. Detailed elevation data along the California coast using LiDAR will allow resource managers and coastal community planners to assess and plan for impacts from sea level rise, as well as sudden inundation, such as tsunamis or storm surges. It will also contribute to wetland restoration planning, floodplain management, storm water management, coastal development, and rapid post-event (e.g., large storms) responses.

Gradual Inundation of Low-lying Developed Shoreline Areas

The developed areas landward of Cowell's and Main beaches are protected by a concrete seawall, which provides protection from any high tides or storm wave runoff. While driftwood and debris have been carried up to the wall during large recent El Niño events (**Figure 11**), a significant increase in sea level and/or a more severe wave climate would be required to overtop the wall. Given present projections, this is not expected to happen by 2050. When this becomes a problem, the top of the wall could be raised or retrofitted.

The west side of the Santa Cruz Small Craft Harbor is another low lying area which is reported now to be overtopped at very high tides. A similar retrofit could be developed in order to raise the bulkhead along this side of the harbor at the point where overtopping becomes a more frequent and hazardous occurrence.

The sewage pumping station along West Cliff near Almar Avenue should also be assessed to determine at what sea level elevation some retrofitting might be necessary, although this is not believed to be a near-term issue.

There is very little undeveloped low-lying shoreline property along the city shoreline although there are several redevelopment proposals, including the new Monterey Bay National Marine Sanctuary Exploration Center and the new hotel proposed for the La Bahia site. These sites lie at elevations of 12-13 feet and 14 feet and higher, respectively, so are not considered to be vulnerable under present sea level rise and storm wave projections until the 2050-2100 period at the earliest.

Gradual Inundation of Public Beaches Where Back Edge of Beach is Fixed by a Structure

Where a coastline has not been altered by human activity, the beach and shoreline will migrate landward or inland as sea level gradually rises. This took place along all of the Monterey Bay area shoreline during the sea level rise of the past 18,000 years. Where the shoreline has been fixed, however, such as the entire length of Beach

Street between the Dream Inn and the east end of the Boardwalk, sea level rise will gradually inundate or flood the beach because the beach cannot migrate inland (**Figures 13a, b, c, and d**). This will be a progressive process related to the future rate of sea level rise. Given the present projections of 1.4 feet of rise by 2050 (**Figure 6**), **Figures 13b and c** provide some perspective on how this will affect Main Beach. The consequence will be gradual loss of beach area at high tides. There are no reasonable or practical measures for reducing this impact.

Rise in Groundwater Table Beneath Sewage Treatment Plant

A high water table beneath the sewage treatment plant in Neary Lagoon is already a concern. Borings in 1985 indicated a water table at a depth of about five feet. Over the near-term, the plant can tolerate some additional rise. Over the longer term (2050-2100), if sea level were to rise an additional 3 to 4 feet, operations would become compromised and adaptive responses would be necessary. One approach would be to engineer a cut-off wall, such as a steel sheet pile barrier and/or a grout curtain, in order to try to isolate ground water beneath the plant from the rest of the Neary Lagoon area and then utilize pumping to keep ground water levels to an acceptable level. If this is feasible, it could produce acceptable conditions until perhaps the end of the century. Relocating the entire plant is a much longer-term approach, and one that needs to be factored in to long-term planning as the present plant ages and sea level continues to rise to unacceptable levels.

Rise in Groundwater Table Beneath the Downtown Area

There have been high groundwater table concerns for decades in the downtown portion of the city. Typically the water table is only 4 to 8 feet beneath the surface but occasionally may rise to within two feet of ground level. This affects a very large area with strong hydraulic connectivity to the water level in the San Lorenzo River, which is strongly influenced at present by tidal cycles and levels and will be affected in the future by sea level rise. Adaptation options are limited and have been underway for years: water is pumped from some problem areas back into the river, and most of the basements have apparently been abandoned, many after the damage and demolition associated with the 1989 earthquake. Adaptive responses are limited and include abandonment of any remaining basements and increased pumping to maintain acceptable water table levels. Impacts of a continued water table rise on below ground utility infrastructure (e.g. electrical cables and junction boxes) may be an additional concern depending upon the nature of the utilities and depth of burial.

Increased Frequency and Intensity of Coastal Storms

An increased frequency and magnitude of storm wave attack, including greater wave heights, is predicted to accompany climate change. Average wave heights have been gradually increasing over the past several decades along the central and northern California coast. For the Santa Cruz coast, these trends combined with a

gradually rising sea level, translate into more frequent overtopping of the low areas along West Cliff Drive, which already takes place (**Figure 8**). More wave energy being expended against the cliff can also be expected to increase the risk and rate of coastal cliff retreat.

Increase in Cliff Erosion Rates

Adaptation options include retreating from those severely threatened areas, which might require eventually relocating the pathway along West Cliff inland. This could involve reducing the width of West Cliff Drive to a single lane and creating one-way traffic. This was the solution for threatened portion of East Cliff Drive in the Pleasure Point area, along with a soil nail wall to stabilize the bluff. Most of the hazardous areas where the cliff edge is closest to the bike path have already been armored, however. The remaining areas of highest future risk are concentrated in the area of West Cliff between Almar Avenue and the Lighthouse, and between the Lighthouse and Manor Avenue. Although there are some dramatic areas of bluff retreat due to the collapse of natural bridges and arches (Figures 15 and 16), historic erosion rates in this area have been only moderate (Griggs and Ross, 2006). Notwithstanding a very large increase in wave height and energy, and a significant increase in the rate of sea level rise, these are not believed to be major threats in the decades prior to mid-century. The area of highest public safety risk due to intensity of use is the ultimate collapse of either or both of the caves that penetrate Lighthouse Point. The most appropriate adaptation here would be regular observation and surveying and continuing to relocate the pathway further from the cliff edge.

While there are areas along West Cliff that are unarmored and other areas where the existing armor is occasionally overtopped, most severely threatened areas have now been protected. With the Coastal Commission's hesitancy to approve any new armoring along the state's coast unless the structure or infrastructure involved is within one or two storm cycles of being undermined or damaged, it will become increasingly more difficult to obtain permits to install additional riprap or seawalls. Nonetheless, a complete assessment of the areas along West Cliff presently threatened by cliff erosion and winter wave overtopping is a first step in determining priorities for future retreat, augmentation of existing protection or additional armor placement. Although this may not occur until mid-century, sea level rise of two feet combined with increased wave attack will elevate risks along the city's coastal to the point where adaptation decisions will need to be made.

Increased Frequency of Storm Surge and Wave Run-Up

Wave overtopping is difficult to eliminate, although low areas like the Bethany Curve Bridge, can be rebuilt at a higher elevation with a curved return wall on the seaward side of the bridge to reduce overtopping. Where the pathway follows the bluff top, adaptation over the next several decades may involve simply restricting pedestrian traffic during high tide or large wave events and then cleaning up the wave thrown debris afterwards.

Changing Patterns of Seasonality of Precipitation

Santa Cruz is well aware of its dry-season water supply challenges, and has short-term and long-term drought contingency plans. The challenge posed by climate change is to revisit existing plans from the perspective of possible greater frequency, duration, and intensity of droughts. The City shares both its surface waters and its groundwater resources with other water users. The Water Department should take a regional perspective and review what other agencies are planning to do in an intense summer drought, including the possibility of a more regional solution. The City maintains open purchase orders with local companies that it can exercise during emergencies of any kind. The purchase orders are managed as part of their Emergency Operations readiness. This preparedness should include the potential threats from increased drought due to climate change.

The City is exploring the potential for a seawater desalination plant for augmenting the current supply to be used in summer drought situations. This plant could provide a measure of safety in major drought situations and operate for several decades. Construction plans for the proposed facility should take into account the possibility of sea level rise and coastal inundation, as well as power outage risk. The possibility of lower-cost incremental expansion of the plant should also be considered if drought conditions return more frequently and intensely in the future. This entails providing/acquiring a building that has room for addition of additional water treatment “skids,” and sizing ocean intake pipelines and produced water pipelines to accommodate additional capacity without complete rebuilding.

The Bay Street Reservoir is the City’s major terminal storage point for treated, potable water. If climate-change-related incidents reduce the treatment capacity of the Graham Hill Treatment Plant, additional storage capacity at Bay Street would provide extra time to correct the problem. Issues at Graham Hill could include unexpected high water turbidity that shuts down the intakes, or invasion of difficult-to-treat microbial species due to warmer temperatures that require temporary stoppage of the treatment process while the problem is addressed. However, the City is limiting the volume of treated water storage in order to meet water quality requirements. The entire system at present will store approximately one day of treated water for emergency purposes due to the water quality degradation associated with long residence times. The addition of treated water storage as well as its location is a function of *daily* water demands and system hydraulics rather than longer-term emergencies. For these reasons it is doubtful that expanded treated water storage will play a role in climate adaptation.

Higher Temperatures and Lower Rainfalls

An important theme of climate change adaptation is that numerous climatic factors could combine in ways that tax the response capabilities of

municipalities. The combination of increasing intensity and increasing frequency of climate events suggests that overlap of events may occur more frequently. The iterations are endless, and not all can be prepared for. But some should be considered in light of Santa Cruz's physical setting next to both substantial wild land areas and proximity to the ocean. The combination of higher temperatures and lower rainfall is one example.

Increased risk of Wildfires

Wild land-urban interface (WUI) zones present fire hazards to people and structures. Wild lands combine a ready fuel source and limited fire-fighting access and infrastructure. Fires initiated in wild lands can enter urban areas, causing widespread impacts. Santa Cruz has extensive wild land greenbelts and parks on its western and northern sides, as well as west-side undeveloped ravines. Some regions are currently rated moderate fire risks; others high fire risks. Several regional large wild land fires during the summers of 2008 and 2009 reminded residents of these risks.

Climate-change-related impacts point in the direction of increased frequency and different intensity of wild land fires. Frequency may increase due to expected longer and more severe heat waves and droughts, thereby increasing the flammability of brush. The possibility of multiple simultaneous fires also is increased. Intensity could change due to the succession of wild land plant species that may have different fire characteristics. The City should review and revise its existing fire response plans to account for the changing risk profile presented by fires in the WUI.

Adaptation steps include reviewing mutual aid agreements in terms of multiple-fire risks both within and outside the city borders, given that heat waves could cover hundreds of square miles. Issues include response time and available outside resources. In terms of Emergency Operations, the City's Emergency Operations Center coordinates the City's response to structural, transportation, utility, public health, and other impacts of a fire. Emergency operations procurement officers should evaluate existing stockpiles and open purchase orders for their sufficiency given that the likely duration and intensity of fire (as well as flood and storm) emergencies could increase.

Another adaptation is to accelerate fuel management programs in the WUI. Fuel management involves the removal or thinning of brush that could contribute to the movement and intensity of a fire. Another approach involves creating fuel breaks that slow or stop the movement of fires toward structures. It is possible to engage in fuel management in ways that are consistent with ecological, aesthetic, and recreational goals. The Fire and Public Works departments have plans for fuel management on public lands. In light of climate change, these plans should be reviewed and implemented starting with the high fire risk zones and proceeding to the moderate fire risk zones.

On private lands in at-risk areas, the Fire Department utilizes a number of volunteer approaches, such as information booklets (“Living with Fire in Santa Cruz County, 2004 “), making wood chippers available, and responding to requests/complaints about weed density or other high-risk conditions. The City and County have direct powers to remove fire-prone weeds from privately held vacant lots, but little control over privately held, developed lots. In general, fire-resistant landscaping should extend 30 feet around at-risk houses, and as much as 100 feet if the house is on a steep, fire-prone hill. At-risk structures should be inventoried and an emergency communications program (e.g., reverse-9-1-1) implemented. Information and training materials, such as the Living with Fire bulletin, should also be distributed in the WUI.

Hotter and Longer Heat Waves

Increasing average global temperature is the most consistent prediction of climate-change models. Models also suggest that climate variability will increase, including high and low temperatures. Longer, more frequent, and more intense heat waves are therefore possible. Santa Cruz heat waves are mitigated by the presence of the ocean, however the temperature differential between Santa Cruz and nearby inland areas during a heat wave could exacerbate the local impacts.

Heat waves create physical discomfort and pose health risks to people who are outside in the sun and to the elderly, disabled, and housebound. The death toll in Moscow during the record-breaking heat of the summer of 2010 doubled to 700 people per day at one point. The City should review its emergency shelter plans in terms of indoor climatic suitability, and invest in upgrading shelters to deal with more intensive heat waves. The City should also review and upgrade its emergency contact programs to at-risk residents. This contact program could involve public-private partnerships among public and private groups, such as churches and synagogues.

It is typical that hot days in Santa Cruz mean sweltering temperatures inland. Several million people live a few hours drive from Santa Cruz. Much of our local commerce depends on daily and weekly summer visitors drawn in part by cooler coastal temperatures. This attraction could grow as summer temperatures grow in surrounding inland areas. In this sense, climate change presents an economic opportunity to Santa Cruz to expand its summer tourism offerings. The City should review its economic planning given the potentially larger fluctuations in population in and out of the city. Although likely to take the form of short-term visits to the region, another possibility resembles the well-known winter-summer migration of elderly people between Florida and New England. Santa Cruz may be the New England-equivalent, providing cooler temperatures to summertime residents who live elsewhere during the winter.

While economically beneficial to the City, increasing our average summertime population will increase the strain on public resources. Police, Fire, Parks &

Recreation, Water, and Emergency Operations should review their emergency plans in light of potentially greater influxes of visitors during the hottest periods of summer. Scenarios of interest involve fires, water emergencies, or heat waves at times of maximum population within the City, including homeless and minimal-income transients. Another risk is regional power outage that could result from too much demand on the power grid or reduced power supply due to extended droughts reducing hydropower availability of PG&E. The City should contact PG&E and clarify its power outage risk, and then review its plans, resources, and contracts for peak-period summer power outages.

Some Final Thoughts

We don't get to vote on whether the climate is changing. Climate changes are already underway within California and are likely to increase in the years ahead. Expected changes to local climate include: 1] overall higher temperatures, 2] longer droughts and more frequent wild land fires, 3] water shortages, 4] changes in precipitation patterns including less snowfall and more concentrated winter rainfall, runoff and associated flooding, 5] sea level rise and shoreline inundation, and 6] larger storm waves. These changes will affect our shoreline and coastal ocean through rising ocean temperatures and acidification, changes in ocean productivity, and an increasing risk to our coastal communities and economy, including fisheries, beaches and recreation, shoreline development and infrastructure, and ports and harbors.

While uncertainties over exactly how climate change will reverberate through the state remain, that uncertainty shouldn't result in paralysis or lack of action. Planning for climate change is fundamentally a risk management strategy, an insurance policy against an uncertain future. Managing these risks involves using the best available science to understand the likelihood of climate impacts and their associated consequences, and then selecting and implementing the most effective response options.

The debate on certain fundamental points regarding climate change is over: global climate change is real, and it's caused primarily by human activities. We are already seeing the effects, and new observations, findings and impacts appear regularly. The risks of future changes that will affect our weather and consequently our communities, agriculture, health, and economy are substantial unless actions are taken now.

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