

THE IMPACTS OF SEA-LEVEL RISE ON THE CALIFORNIA COAST

Executive Summary

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Arnold Schwarzenegger, *Governor*

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California's coastline, which includes more than 2,000 miles of open coast and enclosed bays, is vulnerable to a range of natural hazards, including storms, extreme high tides, and rising sea levels resulting from global climate change. Development along California's coast is extensive. In 2003, more than 30 million Californians lived in coastal counties, and this number is rising. Major transportation corridors and other critical infrastructure are found along the California coast, including oil, natural gas, and nuclear energy facilities, as well as major ports, harbors, and water and wastewater plants. The California coast is also an extraordinary cultural and ecological resource and offers extensive tourism and recreational opportunities.

Flooding and erosion pose a threat to communities along the California coast and there is compelling evidence that these risks will increase in the future. Based on a set of climate scenarios prepared for the California Energy Commission's Public Interest Energy Research (PIER) Climate Change Research Program, Cayan et al. (2008) project that, under medium to medium-high emissions scenarios, mean sea level along the California coast will rise from 1.0 to 1.4 meters (m) by the year 2100.¹ Rising seas put new areas at risk of flooding and increase the likelihood and intensity of floods in areas that are already at risk. In areas where the coast erodes easily, sea-level rise will likely accelerate shoreline recession due to erosion. Erosion of some barrier dunes may expose previously protected areas to flooding.

National studies on the economic cost of sea-level rise suggest that while adapting to climate change will be expensive, so are the costs of doing nothing, as substantial investments are already at risk and vulnerable.² Because the economic costs of flooding are highly site-specific, regional analyses are critical for guiding land-use decisions and evaluating adaptive strategies.

The Pacific Institute published one of the earliest comprehensive regional assessments of sea-level rise (Gleick and Maurer 1990), concluding that a one-meter sea-level rise would threaten existing commercial, residential, and industrial structures around San Francisco Bay valued at \$48 billion (in year 1990 dollars). Building or strengthening levees and seawalls simply to protect existing high-value development was estimated to require an immediate capital investment of approximately \$1 billion (in year 1990 dollars) and would require an additional \$100 million per year in ongoing maintenance.³ The report also noted that substantial areas of the San Francisco Bay, especially wetlands and marshes, could not be protected and would likely be damaged or lost.

This assessment updates and expands our 1990 analysis using more comprehensive data, new climate scenarios, and modern computerized analytical tools. We made extensive use of geographic information system (GIS) software and updated sea-level rise scenarios from the

¹ It is important to note that most climate models fail to include ice-melt contributions from the Greenland and Antarctic ice sheets, and as a result, the potential increase in mean sea level may be much higher.

² See, for example, Titus et al. (1992) and Yohe et al. (1996).

³ This estimate does not include the cost of protecting and restoring wetlands, groundwater aquifers, etc.

Scripps Institution of Oceanography to estimate the population, infrastructure, ecosystems, and property at risk. We also estimate the cost of armoring the coast, one potential adaptation strategy to reduce that risk. This work is part of a larger set of research projects by the California Climate Action Team to understand the impacts of climate change to Californians, funded by the California Energy Commission's Public Interest Energy Research (PIER) program. The Pacific Institute also received significant financial support from two other state agencies: the Ocean Protection Council and the Metropolitan Transportation Commission, part of the Department of Transportation.

Key Findings

Over the past century, sea level has risen nearly eight inches along the California coast, and general circulation model scenarios suggest very substantial increases in sea level as a significant impact of climate change over the coming century. This study includes a detailed analysis of the current population, infrastructure, and property at risk from projected sea-level rise if no actions are taken to protect the coast, and the cost of building structural measures to reduce that risk. We find the following:

- Under medium to medium-high greenhouse-gas emissions scenarios, mean sea level along the California coast is projected to rise from 1.0 to 1.4 meters (m) by the year 2100. A series of maps for the entire coast of California demonstrating the extent of the areas at risk are posted at www.pacinst.org/reports/sea_level_rise.⁴
- A 1.4 meter sea-level rise will put 480,000 people at risk of a 100-year flood event, given today's population. Populations in San Mateo and Orange Counties are especially vulnerable. In each, an estimated 110,000 people are at risk. Large numbers of residents (66,000) in Alameda County are also at risk.
- A demographic analysis identified large numbers of people at risk with heightened vulnerability, including low-income households and communities of color. Additionally, adapting to sea-level rise will require tremendous financial investment. Given the high cost and the likelihood that we will not protect everything, adaptation raises additional environmental justice concerns.
- A wide range of critical infrastructure, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants, power plants, and more will also be at increased risk of inundation in a 100-year flood event. This infrastructure at risk includes:
 - Nearly 140 schools;
 - 34 police and fire stations;

⁴ These maps are not the result of detailed site studies and were created to quantify risk over a large geographic area. They should not be used to assess actual coastal hazards, insurance requirements or property values, and specifically shall not be used in lieu of Flood Insurance Studies and Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA). Local governments or regional planning agencies should conduct detailed studies to better understand the potential impacts of sea-level rise in their communities.

- more than 330 U.S. Environmental Protection Agency (U.S. EPA)-regulated hazardous waste facilities or sites, with large numbers in Alameda, Santa Clara, San Mateo, and Los Angeles counties;
 - an estimated 3,500 miles of roads and highways and 280 miles of railways;
 - 30 coastal power plants, with a combined capacity of more than 10,000 megawatts;
 - 29 wastewater treatment plants, 22 on the San Francisco Bay and 7 on the Pacific coast, with a combined capacity of 530 million gallons per day; and
 - the San Francisco and Oakland airports.
- Vast areas of wetlands and other natural ecosystems are vulnerable to sea-level rise. An estimated 670 square miles, or 430,000 acres, of wetlands exist along the California coast, but additional work is needed to evaluate the extent to which these wetlands would be destroyed, degraded, or modified over time. A sea-level rise of 1.4 m would flood approximately 150 square miles of land immediately adjacent to current wetlands, potentially creating new wetland habitat if those lands are protected from further development.
- We estimate that nearly \$100 billion (in year 2000 dollars) worth of property, measured as the current replacement value of buildings and contents, is at risk of flooding from a 100-year event with a 1.4 m sea level rise if no adaptation actions are taken. An overwhelming two-thirds of that property is concentrated on San Francisco Bay. The majority of this property is residential.
- Coastal armoring is one potential adaptation strategy. Approximately 1,100 miles of new or modified coastal protection structures are needed on the Pacific Coast and San Francisco Bay to protect against coastal flooding. The total cost of building new or upgrading existing structures is estimated at about \$14 billion (in year 2000 dollars). We estimate that operating and maintaining the protection structures would cost approximately 10% of the initial capital investment, or around another \$1.4 billion per year (in year 2000 dollars).
- Large sections of the Pacific coast are not vulnerable to flooding, but are highly susceptible to erosion. We estimate that a 1.4 m sea-level rise will accelerate erosion, resulting in a loss of 41 square miles of California's coast by 2100. A total of 14,000 people live in areas at risk of erosion. In addition, significant transportation-related infrastructure and property are also at risk. Throughout most of the state, flood risk exceeds erosion risk, but in some counties, coastal erosion poses a greater risk.
- Continued development in vulnerable areas will put additional areas at risk and raise protection costs.

Recommendations

Climate changes are inevitable, and adaptation to unavoidable impacts must be evaluated, tested, and implemented. Sea levels have risen observably in the past century, and scientists forecast that sea-level rise will continue for centuries, even if we stop emitting greenhouse gases immediately. As a result, coastal areas will be subject to increasing risk of inundation and erosion. Below, we provide a series of recommendations and principles to guide the adaptation process.

Principles for Adaptation

The decisions about what to protect, how to protect it, and who will have to pay will be both challenging and controversial. Given the complexity of these issues, it is important to develop an open and transparent process involving all affected stakeholders. Below, we provide some general principles to guide this process:

- Human life must be protected.
- Critical ecological systems should be preserved.
- Development and protection of the coast should be governed by the principles of sustainability. Simply stated, this means “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987).
- Equal and full participation must be a central element of any decision-making process. No social or economic group should be excluded from decision-making that will affect its well-being.
- Communities must determine the resources and features they value, e.g., beaches, public access, fisheries, etc., and develop plans to protect those resources.
- Consideration should be given to equitable distribution and apportionment of costs and benefits of adaptation measures.
- Adaptation strategies should account for the distinct vulnerabilities of potentially affected subpopulations.
- Local and regional planning processes must begin early to incorporate estimates of sea-level rise and strategies for adaptation.

Recommended Practices and Policies

Climate change must be integrated into the design of all coastal structures.

Current efforts to build, maintain, or modify structures in coastal areas at risk of sea-level rise must now be based on estimates of that rise. The costs of modifying structures in the design phase are often far lower than the costs of later reconstruction or flood damage.

The federal government and the insurance industry should develop and implement a methodology for integrating climate change into insurance policies and strategies.

Properly designed insurance policies are vital for helping landowners choose whether to protect or abandon risky property. The design, availability, and cost of flood insurance will be a key instrument in implementing floodplain policy. For example, the government should not continue to subsidize flood insurance for properties that have suffered repetitive losses. Nor should insurance be available for properties highly likely to be inundated under future conditions.

Federal flood insurance maps should include information on future flood risks due to sea-level rise.

The Federal Emergency Management Agency's official flood insurance studies show hazard zones that reflect past or present flood risks. Because these are the *de facto* planning documents used by most local governments, they should be updated to show the *future* hazard areas and include the current science on climate change and sea-level rise.

Wetlands and the potential migratory paths should be protected.

Development should be prohibited on natural lands that are immediately adjacent to wetlands at risk. These buffer areas may be the only areas suitable for future wetland restoration projects.

Future development should be limited in areas that are at risk from rising seas.

In regions at risk that are not yet heavily developed, local communities and coastal planning agencies have the opportunity to limit development and reduce future threats to life and property. Policies that maintain such low-lying areas will help to accommodate rising seas. In addition to insurance policies, discussed above, such policies may include local ordinances, statewide coastal development policies, and explicit purchases of land for conservation purposes. This is often the least expensive option for currently undeveloped areas.

While limiting coastal development is the most effective way to reduce risk, this approach can incur costs today. Development permits designed to provide flexibility for future generations to address sea-level rise will reduce today's cost. For example, permits might allow development but stipulate that the area reverts to nature if seas rise by a specified amount.

Local planning processes need to involve communities most vulnerable to harm when developing appropriate preparation and adaptation strategies.

The particular needs of vulnerable communities, and appropriate adaptation policies, are best identified and developed through processes in which the affected communities are at the center of decision making. The vulnerabilities to sea-level rise created by access to transportation, legal residency, income, and language abilities can only be fully understood and protected when members of these communities are directly involved in the process.

Consider phased abandonment of low- and medium-density areas at high risk.

In some low- and medium- density areas, the monetary and environmental cost of holding back the sea may become unacceptably high. The lowest-cost option may be to allow natural processes take place. Policies that prevent flood-damaged homes or businesses from rebuilding may help ease this transition.

Protect vital societal resources, especially those that are “coastal-dependent.”

In many cases, the value of an area’s infrastructure far exceeds the cost to raise structures or build protective barriers. For example, the San Francisco airport and the Port of Long Beach are extremely important to the state and national economy. In choosing what to protect, we should favor infrastructure that necessarily belongs on the coast, such as ports, bridges, and marinas.

Cost-benefit analyses should explicitly evaluate the social and environmental costs of building coastal protection structures.

Armoring the coastline can save lives and property, but it also comes at a cost. The natural dynamics that occur between water and land are disrupted. Beaches and wetlands disappear and habitat is lost. Traditional cost-benefit analyses, such as those required for all US Army Corps of Engineers projects, do not adequately account for these inherent tradeoffs.

Coastal emergencies are inevitable. Coastal communities should improve disaster response and recovery.

In this analysis, we have focused on increased risk of coastal flooding and erosion as a result of sea-level rise. California is also subject to tsunamis, earthquakes, wildfires, terrorist attack, and other hazards. Improving community preparedness provides benefits for responding to any type of emergency. Before a disaster strikes, communities must plan for evacuation routes, emergency action plans, and shelters, and take into account the specific needs of vulnerable populations. In addition, roles and responsibilities must be clearly defined among local, state, and federal agencies.

Coastal managers should consider adopting the principles of “No Adverse Impact” when designing and permitting flood protection, beach nourishment, and other coastal protection projects.

Current coastal protection projects are often done with no regard for how they will affect adjacent portions of the coast. According to the Association of State Floodplain Managers: “Over the past 50 years a system has developed through which local and individual accountability has been supplanted by federal programs for flood control, disaster assistance, and tax incentives that encourage and subsidize floodplain occupation and development.” We recommend that coastal managers consider adopting a policy similar to “No Adverse Impact” where the “actions of one property owner are not allowed to adversely affect the rights of other property owners” (ASFM 2008).

Additional Research and Analysis

Local governments or regional planning agencies should conduct detailed studies to better understand the potential impacts of sea-level rise in their communities.

The analysis presented here provides an initial estimate of the impacts of sea-level rise along the California coast. More detailed assessments of local impacts and potential response strategies are needed. While the effects of sea-level rise, responses, and threatened resources must all be evaluated at a local level, broader regional effects must also be incorporated into final protection strategies.

Our analysis was hindered by inadequate data on existing coastal structures. Existing levees and other flood defenses should be surveyed, assessed, and cataloged.

The U.S. Congress passed the Water Resources Development Act of 2007, creating a National Levee Safety. The act requires the establishment and maintenance of an inventory of the nation’s levees and inspection of all federally owned, operated, or constructed levees. This program should be fully funded and quickly implemented, and the information it compiles should be made readily available to residents, local government, and others.

Conduct further research focused on all vulnerable subpopulations, including children, elderly, homeless, physically disabled, and people with limited mobility (e.g., incarcerated residents and healthcare facility patients), accurately measuring and analyzing the potential human costs of sea-level rise and adaptation measures.

This analysis does not include various demographic groups that can be expected to have unique vulnerabilities to potential disasters. For pre-disaster, disaster response, and recovery efforts to effectively safeguard all Californians, further study is needed to identify all vulnerable populations and assess the unique vulnerabilities of each group.

Assess the environmental justice implications of potential mitigation measures, and develop strategies to effectively safeguard all communities.

The measures taken to adapt to sea-level rise must not distribute costs and benefits of protection in ways that place a disproportionate burden on the low-income households and communities of color who are most vulnerable to a potential disaster. The means of prioritizing protection measures must be analyzed with and held to the principles of environmental justice.

Natural ecosystems are at serious risk from sea-level rise, but are undervalued or ignored in traditional economic analyses. Improved methods for incorporating them into future studies are needed.

Wetlands are highly diverse ecosystems that provide a variety of goods and services, including flood protection, water purification, wildlife habitat, recreational opportunities, and carbon sequestration. Large tracts of wetlands along the California coast are vulnerable to sea-level rise. No satisfactory method for incorporating their environmental values has been developed, and we thus risk ignoring them when we make policy decisions. This would be a serious mistake. Additional work is needed to evaluate the costs and values of natural ecosystems.