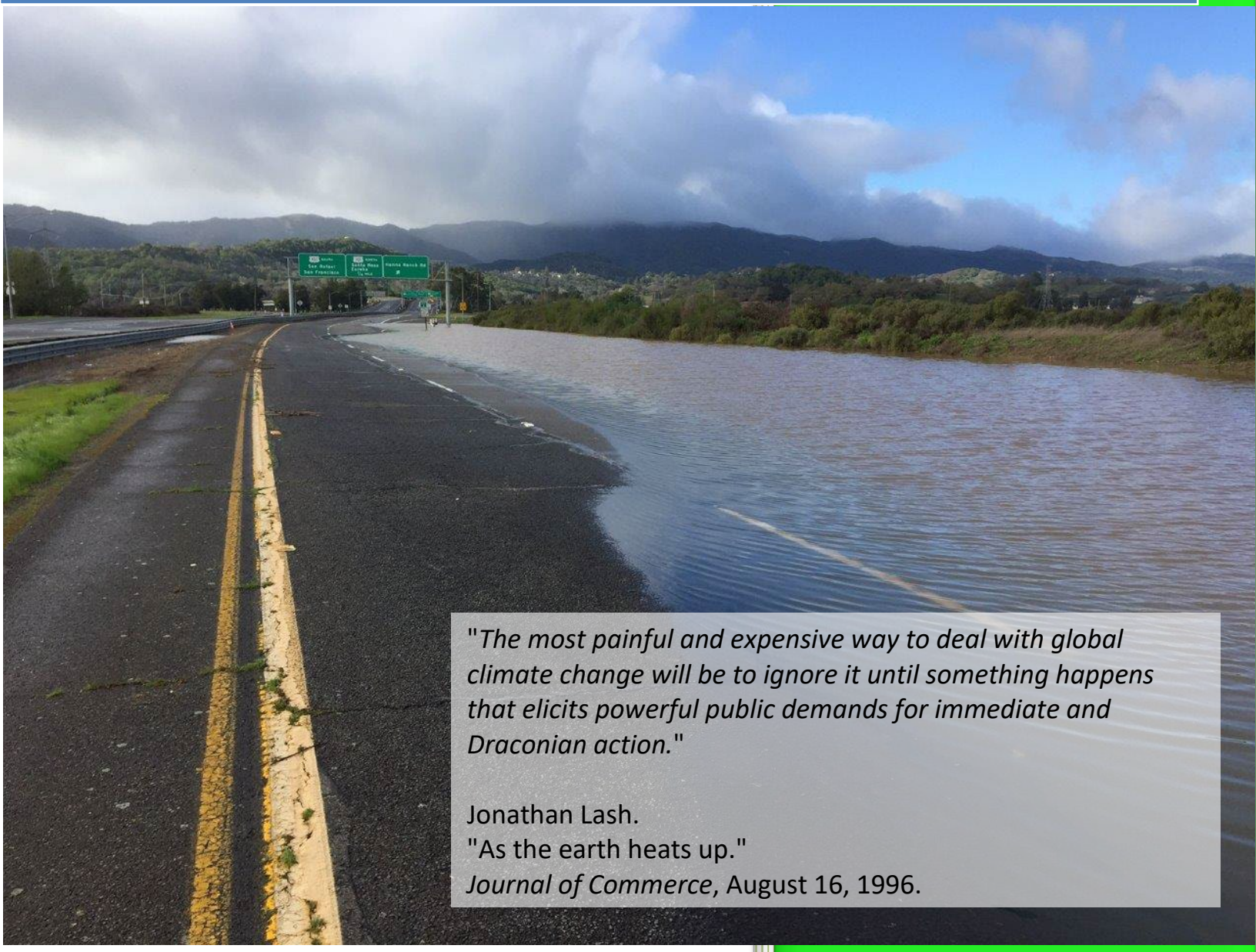
Coastal Flooding Risks for California



"*The most painful and expensive way to deal with global climate change will be to ignore it until something happens that elicits powerful public demands for immediate and Draconian action.*"

Jonathan Lash.
"As the earth heats up."
Journal of Commerce, August 16, 1996.

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Coastal Flooding Risks for California

A Special Report for Winter 2026/27

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Highway 37 flooding during an average El Nino, 2017

Author Note & Acknowledgements

This report relies on previous research in the North San Francisco Bay, extending back to 2011 and involving multiple partners, stakeholders and funders. Some of the information can be found on the highway 37 web-site: http://hwy37.ucdavis.edu. I would like to acknowledge the critical efforts of Katie Benouar and Kome Ajise (originally in Caltrans, Headquarters) throughout the inception and conducting of the Highway 37 project. Thanks to the >200 stakeholder organizations and individuals who contributed their time, ideas, and critical feedback during the Highway 37 project. The research that formed the foundation of this report was supported by: 1) Transportation Research Board contract SHRP C-21(C), 2011; 2) Caltrans contract 74A0728, as part of the State Planning & Research Grant program, 2013; 3) USDOT grant to the National Center for Sustainable Transportation, 2015; and 4) Center for Transportation, Environment, and Community Health grant, 2017 & 2020.

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Executive Summary

Coastal areas in California are likely to face enhanced flooding and erosion risk this winter from a combination of sea level rise and El Nino. All the problems we are seeing now were predicted years ago and we should not be surprised when they start happening (i.e., believe scientists). There are also things we can still do and should do to minimize future risk without causing havoc on the coastline.

Coastal Areas at Risk, Winter 2026/27

There are two important events converging on the California coastline this winter – a legacy of 1 foot of sea level rise from anthropogenic climate change and one of the strongest, if not the strongest El Nino in the last century. These conditions could result in temporary elevation in sea level as a result of thermal expansion of the ocean, the "Kelvin wave" topping 1 foot originating from the warming eastern Pacific, and frequent storm tracks pushing the ocean into the coast. Areas in Southern California exposed to these conditions and not particularly exceptional hurricane surf have already faced historic flooding (Figure 1). In the winter of 2019, North San Francisco Bay's Highway 37 closed due to flooding after a series of "atmospheric river" storms elevated the near-coastal ocean by ~10" and this was during a weak El Nino year. It's reasonable to expect that a combination of these effects, combined with waves on the open coast, or heavy rainfall runoff could cause exceptional coastal flooding and erosion.



Social media post of sunny day flooding in Newport Beach, October 10, 2026

The areas listed here are most at risk for coastal flooding, loss of beaches, loss of shoreline houses, temporary or permanent loss of infrastructure due to erosion and flooding, and temporary or permanent alteration of coastal bluffs, marshes and mudflats. The map below (Figure 2) identifies areas with moderate risk or low costs of damage (orange circles, $millions) and areas with high risk or high costs of damage (red circles, $tens of millions). Important caveat: these are examples of high-risk areas and are NOT the only areas of risk.

A. San Luis Obispo county beaches and roadways (e.g., Avila and Pismo Beaches)

B. Elkhorn Slough area, including Moss Landing, local roads and fields. Santa Cruz shoreline, including beaches, houses, and local roads.

C. South San Francisco Bay local roads, residential areas and marshes. SF International Airport. East Bay marshes. I-80/Bay Bridge eastern approach and West Oakland.

D. Corte Madera US 101 and local roads/marshes. San Rafael residential, roads, marshes. Highway 37 near Novato Creek, east of Petaluma River, near Tolay Creek, west and east of Mare Island.

E. Stinson Beach beachfront, houses and local roads.

F. Humboldt Bay, local roads, fields, US101, marshes.

These areas are shown in more detail in the "Findings" section of the report below.

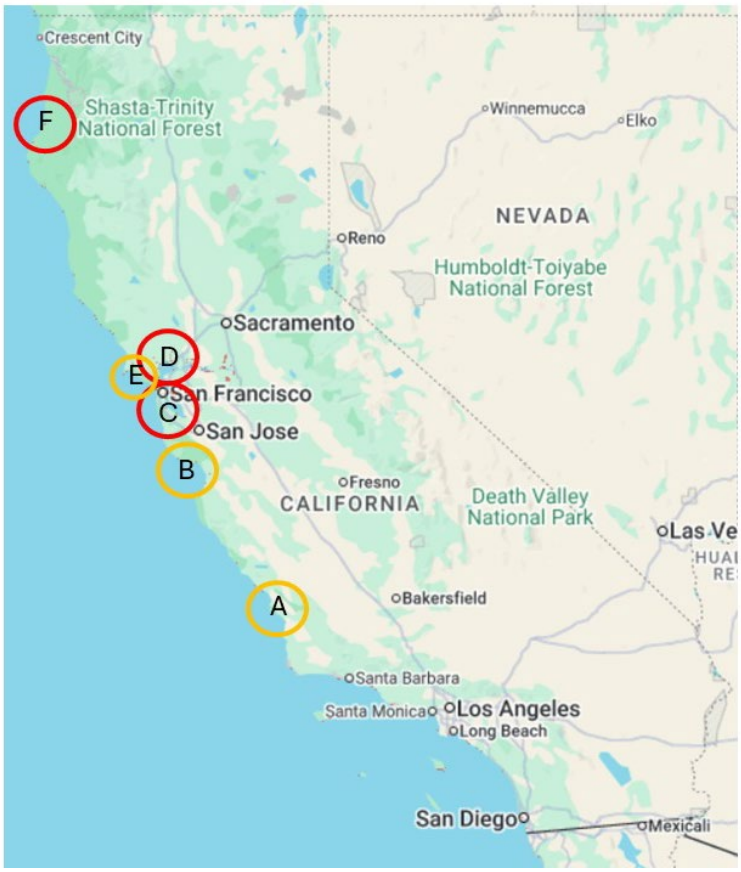


Figure 2. Map of likely 2026/27 winter flooding areas in central and northern California.

Depending on the timing and location of storms, high tides, and stormwater runoff, the flooding could be profound and historic, or only result in temporary inconvenience and expense. The important thing here is RISK. The risk could be composed of low to moderate probability of failure of systems, but still result in high costs. For example, failure of the state and privately-owned levee east of Petaluma River in North San Francisco Bay would result in extensive flooding and at least temporary closure of highway 37. Alternatively, the risk could be composed of a very high probability of failure and the result could be low or high costs. In addition to the risk from failure, it's important to consider how resilient the places are to flooding and erosion. It is possible that the beach flooding in Southern California is resulting in irreversible damage to the beaches of Long Beach and Newport Peninsula areas which even extensive riprap and sand augmentation won't solve. This could be true in other areas too, especially in areas with extensive levees where the protected land is very much lower than the water level and flooding would be rapid and long-lasting (e.g., levee protected areas in the San Francisco Bay area).

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Coastal areas in California are likely to face enhanced flooding and erosion risk this winter from a combination of sea level rise (SLR) and an historically strong El Nino. Some of the conclusions here reflect a study started 15 years ago and finishing 10 years ago focused on State Highway 37 in the North San Francisco Bay. During this and subsequent studies, it became clear that a combination of SLR, storms, and El Nino conditions could cause flooding in the San Francisco Bay and other coastal areas by 2030. All the problems that we are seeing this winter (2026-27) were predicted years ago and we should not be surprised when they start happening (i.e., believe scientists). Many of the scientific citations given below are intentionally greater than a decade old to illustrate this observation. There are also things we can still do and should do so that minimize future risk without causing havoc on the coastline.

Introduction to Climate Change and Sea Level Rise

Identifying infrastructure that is both exposed now or in the future to the ocean and vulnerable to SLR and increased storminess has long been a complicated and potentially expensive process for local and state transportation agencies (Rowan et al., 2014). The physical structures themselves are vulnerable to SLR, which is likely to result in increased costs for maintenance, repair, replacement of facilities and materials, and eventual adaptation (Mallick et al., 2014; Lu et al., 2012). In addition, the function of linked, regional transportation systems may be vulnerable to disruption if one or more SLR-vulnerable link (e.g., a shoreline highway) fails (Testa et al., 2015; Chen et al., 2015).

Sea Level Rise to Date

Sea level has already risen by close to 1 foot along the California coast and by 2100 may be 36” to 66” above present levels (Nicholls, R.J. and A. Cazenave, 2010; NRC 2012). This is without considering updated estimates of the contributions from failing Greenland and Antarctic ice-sheets, which could add feet to these estimates. Climate change is expected to result in accelerated rates of SLR (Cayan et al., 2008) and changing seasonal storm and wave conditions (Bromirski et al., 2013), further exposing the shorelines to impacts (Heberger et al., 2011; King et al., 2011). Infrastructural and living systems adaptations will need to occur to avoid a wholesale change in the marshes, estuarine systems, low-lying urban areas, and exposed highway infrastructure along the US coast. Transportation system and coastal ecosystem changes occur slowly and may not adapt at the rates necessary to keep up with increased sea levels and storminess. Many coastal communities and infrastructural features face risks from storms in the form of flooding, erosion, and shoreline retreat. A longitudinal survey of coastal managers in California found SLR and related problems among the most challenging issues (Finzi Hart et al., 2012).

Projected Sea Level Rise

There is a growing number of predictions of SLR and shoreline change in response to anthropogenic climate change. One alarming study published a decade ago was from a large group of climate scientists (Clark et al., 2016) who positioned the changes in carbon dioxide, temperature and sea level within Ice Age time-scales (+ 10,000 years, Figure 3a). They suggested that focusing on the year 2100 was an unnecessarily short-sighted target for planning as impacts would extent well-beyond the end of the century, affecting future generations. They positioned this long-term thinking in contrast to the conventional economic practice of discounting future impacts (resulting in little incentive to act soon) and suggested that permanent displacement of current shoreline communities should be thought about now, while we are busy creating and benefiting from the climate change resulting in displacement. In addition, the highest rate of change is in the next few centuries, with a rate this century of almost 2 m 100 yr^{-1} (increasing to 4 m 100 yr^{-1} by 2500; Figure 3b), implying that children and grandchildren being born now will see many of the impacts in their lifetimes.

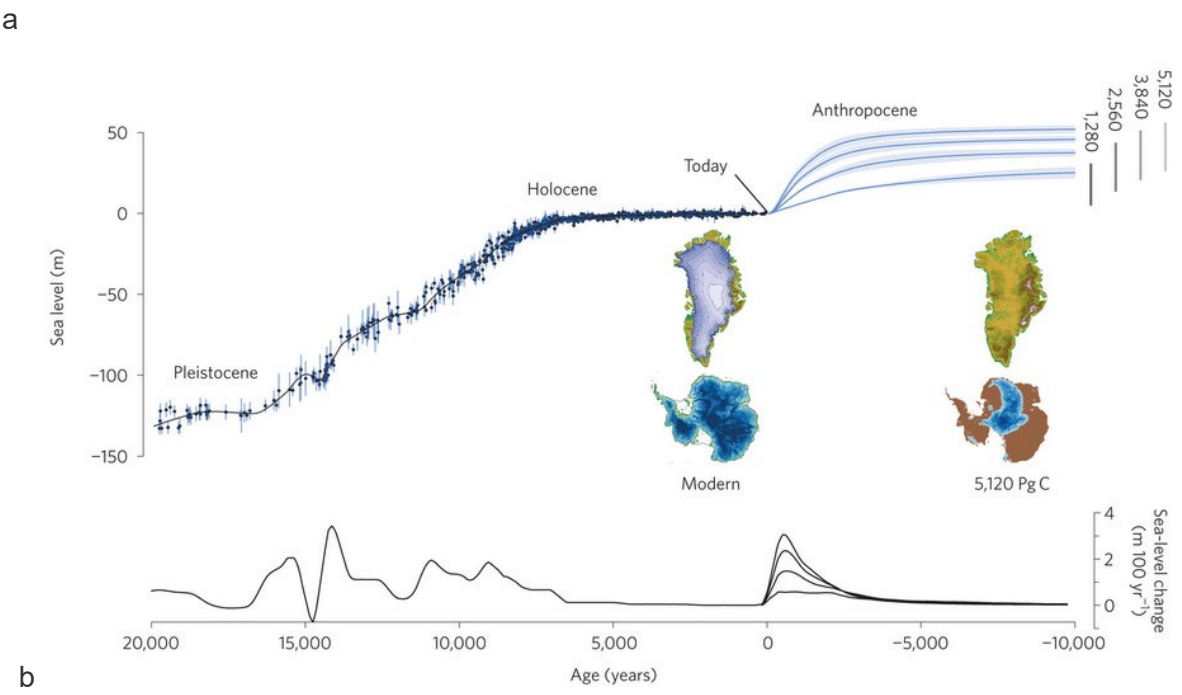
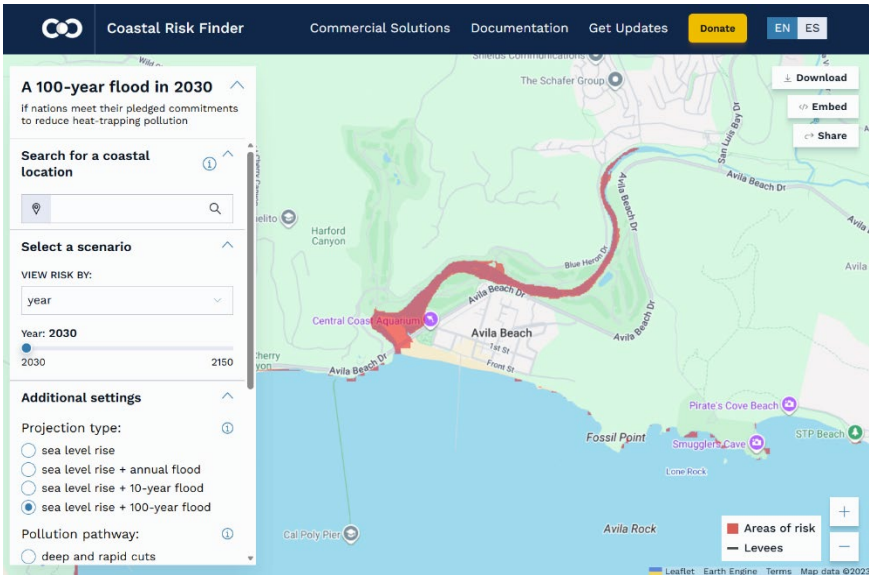


Figure 3. a) Long-term changes in sea level in response to various carbon-emission scenarios (1,280 to 5,120 Pg C) and b) change in rate of sea level rise (m 100 $yr^{-1)}$ for the same emission scenarios (source: Clark et al., 2016).

As can be seen with the scientific literature cited in this section, these are issues that have been well-studied over the last 20 years. Unfortunately, government action has been slow to follow these urgent and careful scientific studies.

Findings and Context

There is a growing number of national and local tools to visualize the predicted inland extent of SLR and shoreline change. One of these is the Climate Central Surging Seas tool (http://ss2.climatecentral.org), which has been around for >10 years. There is a related more recent tool called Coastal Risk Finder (https://coastal.climatecentral.org/coastal-risk-finder). These tools use an underlying shoreline elevation dataset developed by the USGS and NOAA (thanks federal agencies). These tools can be used to gauge what type of flooding conditions we might be facing this winter in California. I used the tools to see which of the SLR and flood (annual vs. 10-year, vs. 100-year) conditions would have resulted in the flooding observed on the Long Beach and Balboa/Newport Peninsulas this October. In general, the degree of street flooding observed is predicted to have occurred with 2 to 3 feet of water elevation, which is similar to existing sea level rise + a 10-year or 100-year flood. These scenarios were used in the tools described above to see where other areas in California might flood from a combination of SLR, El Nino-related ocean and storm conditions, wave action, and stormwater runoff. The sections below describe where flooding could occur, the extent of area affected, and the types of natural and human structures that could be affected. In the maps titled "Coastal Risk Finder", the red areas are at risk of flooding under SLR + 10-year flood or + 100-year flood, which are roughly 2 to 3 feet above current levels. An historic El Nino could bring 100-year flood events. In the maps titled "Surging Seas Risk Zone Map", blue areas are predicted to be flooded and green areas are vulnerable, but protected by levees. The SLR is indicated on the left-hand side of the map with a "2" (2 feet of total sea elevation) or "3" (3 feet of sea elevation).

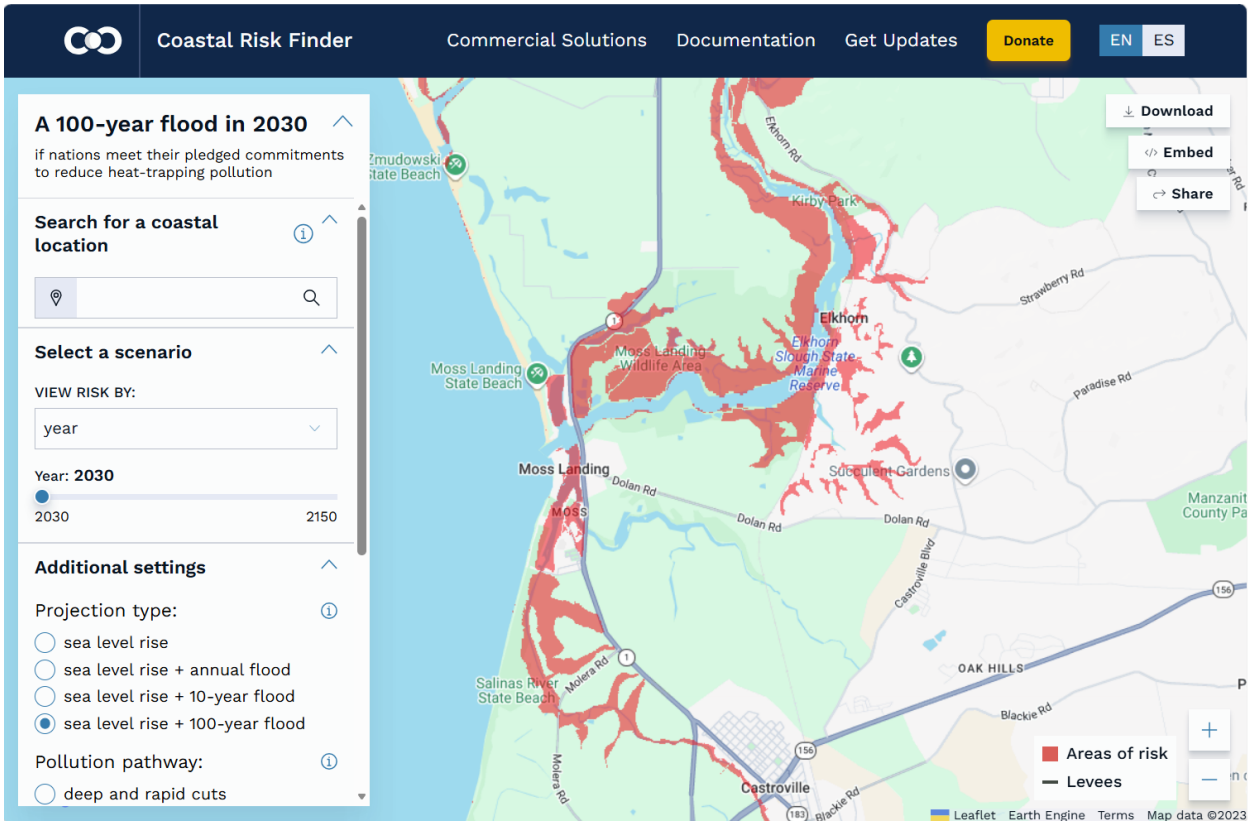


A. San Luis Obispo County beaches, bluffs and roadways (e.g., Avila Beach)

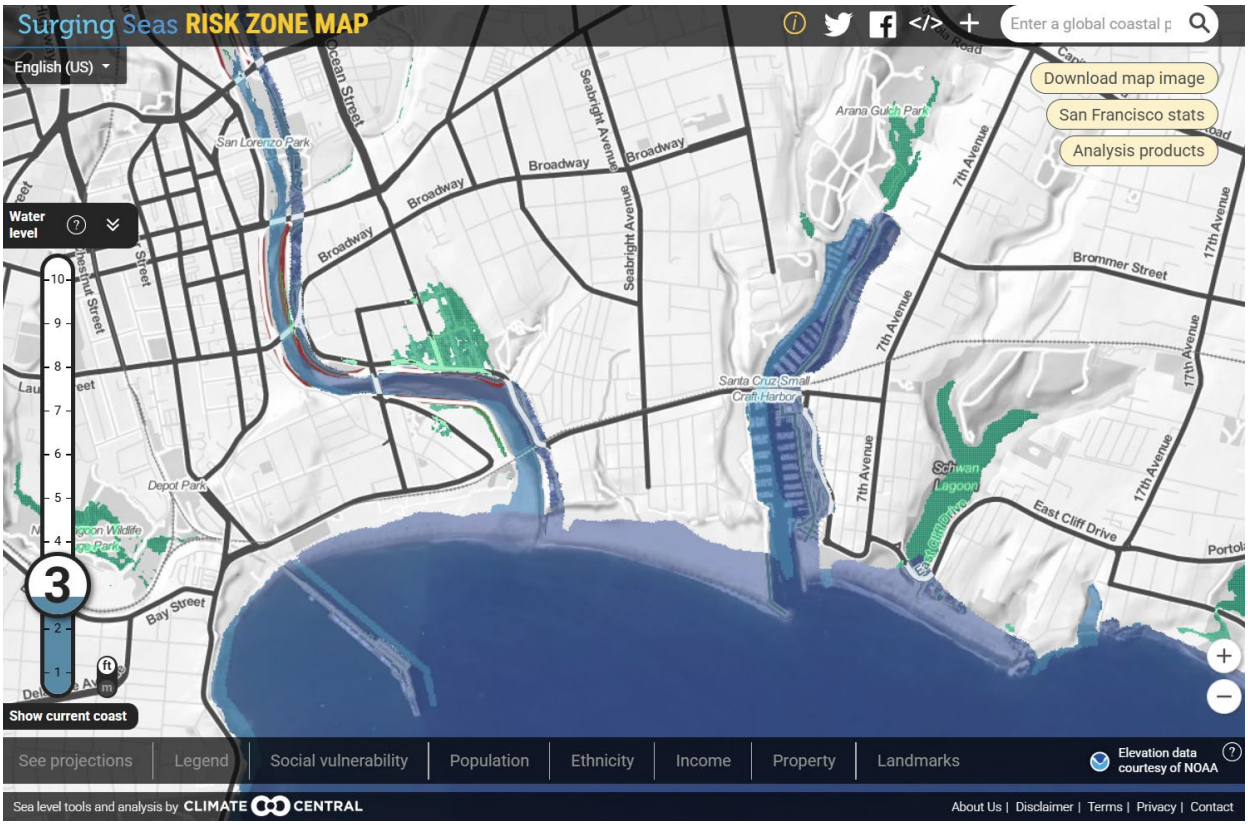
Areas along San Luis Obispo Creek near Avila Beach could experience flooding from a combination of stormwater runoff and high tide (pushing up from the ocean). Bluff areas indicated as small areas of red could experience erosion. Pismo Beach to the south could experience beach loss and a combination of wave action and stormwater runoff could result in flooding adjacent to Pismo Creek. This is a medium-probability, low-impact type of risk.

B. Elkhorn Slough/Moss Landing area, including highway 1, local roads and fields. Santa Cruz shoreline, including beaches, houses, and local roads.

1) A combination of stormwater runoff, high tides, sea level rise and wave action could result in local flooding within Moss Landing, flooding to the edge of highway 1, flooding of marshes and low-lying fields. This is a medium-probability, medium-impact type of risk.



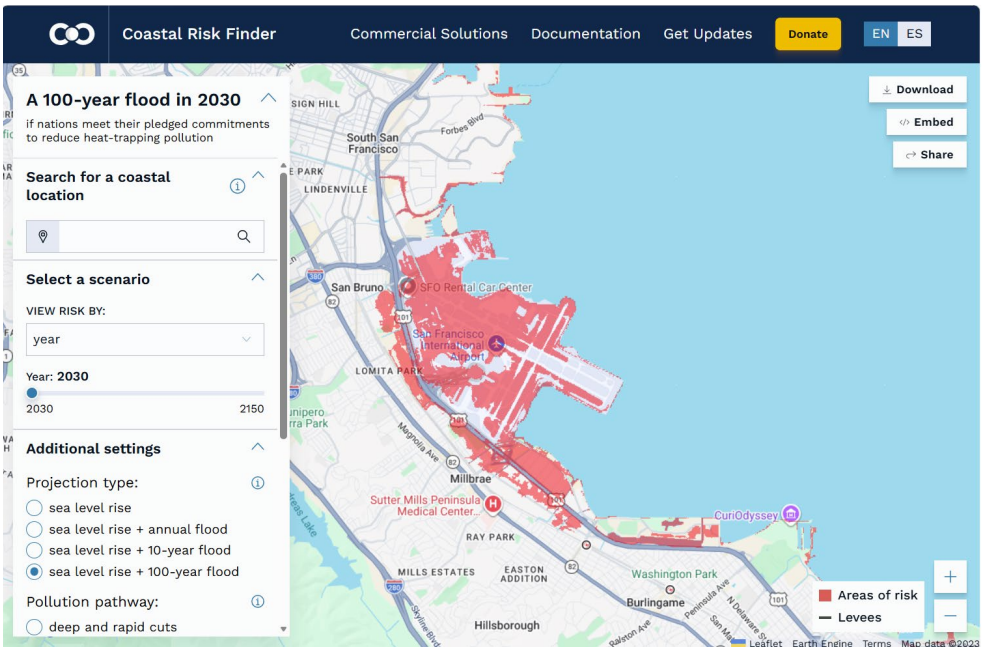
2) Santa Cruz, there could be significant beach loss and localized shoreline flooding and erosion adjacent to the beach and San Lorenzo Creek. This is a medium-probability, medium-impact type of risk. The impacts would be greatest during storms approaching or with wind and wave direction from the south.



2) Santa Cruz City shoreline

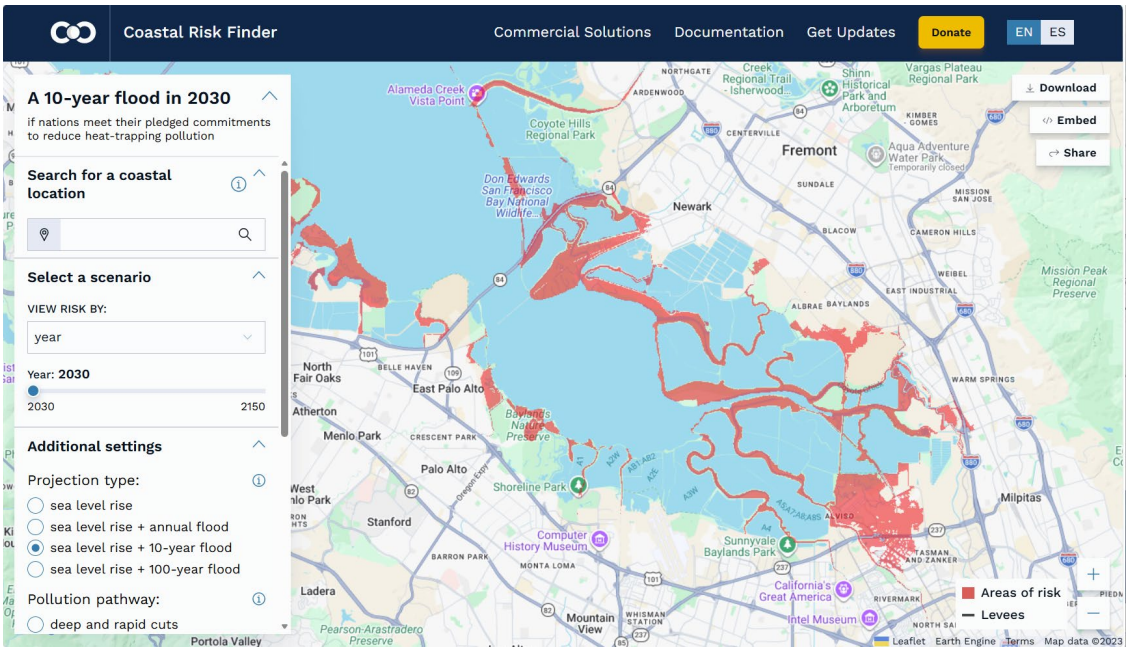
C. 1) SF International Airport. 2) South San Francisco Bay local roads and marshes. 3) East Bay marshes. I-80/Bay Bridge eastern approach, Oakland International Airport and West Oakland.

1) The Bay Area is likely to experience the greatest flooding impacts in areas of former marsh that are now on fill. For example, the San Francisco International Airport is vulnerable to water elevation increases of 3 feet or more. Stretches of US101 adjacent to the airport are also vulnerable. This is a low-probability, high-impact type of risk.



1) San Francisco International Airport

2) The marshes ringing the South Bay and the San Jose communities of Alviso and Renaissance are vulnerable to moderate levels of combinations of SLR, stormwater runoff and high tides. Approximately 2 feet of additional height in sea level (i.e., from SLR and various El Nino effects) could flood portions of these communities.



2) South San Francisco Bay

3) Recent levee improvements at Oakland International Airport have reduced the risk of flooding, except during extreme events, which could occur this winter. The airport flooding is a low-probability, high-impact type of risk. The eastern approach to the Bay Bridge was expanded as part of the overall Bay Bridge project, but did not include SLR as a consideration. The area east of the toll booths is vulnerable to extreme events. This is a low-probability, high-impact type of risk. Certain neighborhoods in West Oakland may be temporarily exposed to flooding during extreme events.

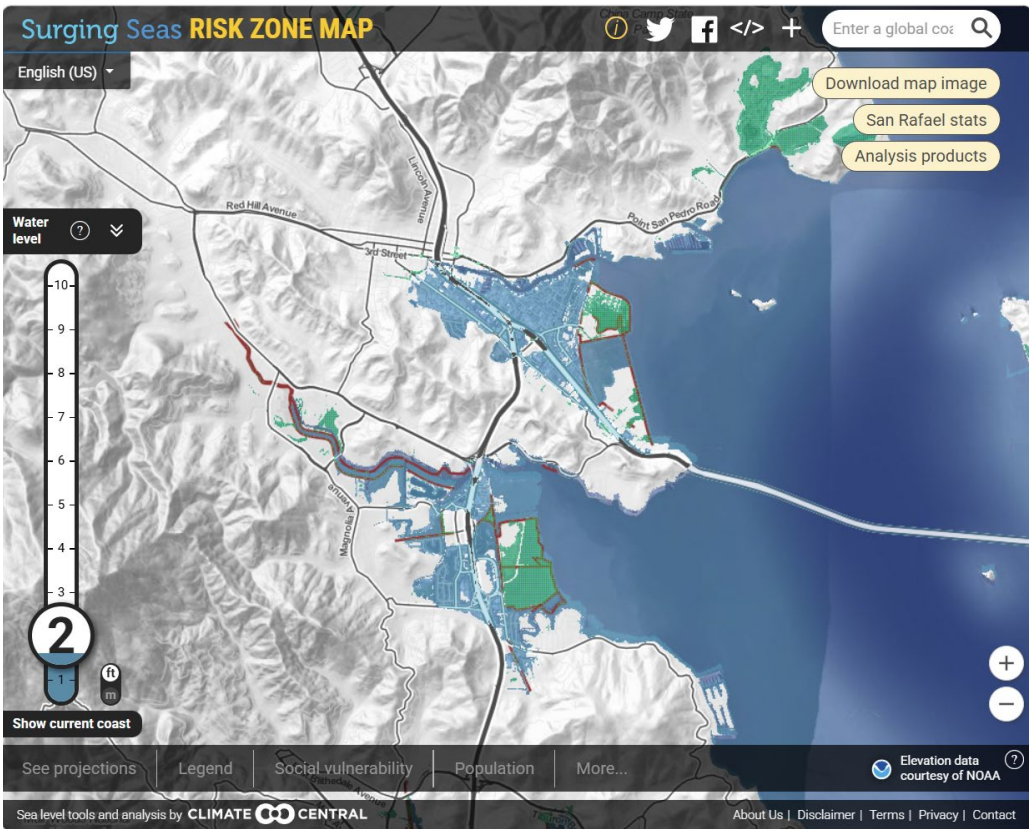


3) Oakland International Airport, West Oakland, I-80/Bay Bridge east approach

D. 1) Corte Madera US 101 and local roads/marshes. San Rafael residential, roads, marshes. 2) Highway 37 near Novato Creek, east of Petaluma River, near Tolay Creek, west and east of Mare Island.

1) US101 passing through Corte Madera is at a low elevation and is vulnerable to temporary flooding during storm events. Local roads, neighborhoods, and marshes are vulnerable to flooding in both San Rafael and Corte Madera. In San Rafael, the Canal Area is very vulnerable

to flooding due to combinations of high tides, stormwater runoff, and sea level rise. This is a medium-probability, high-impact type of risk.



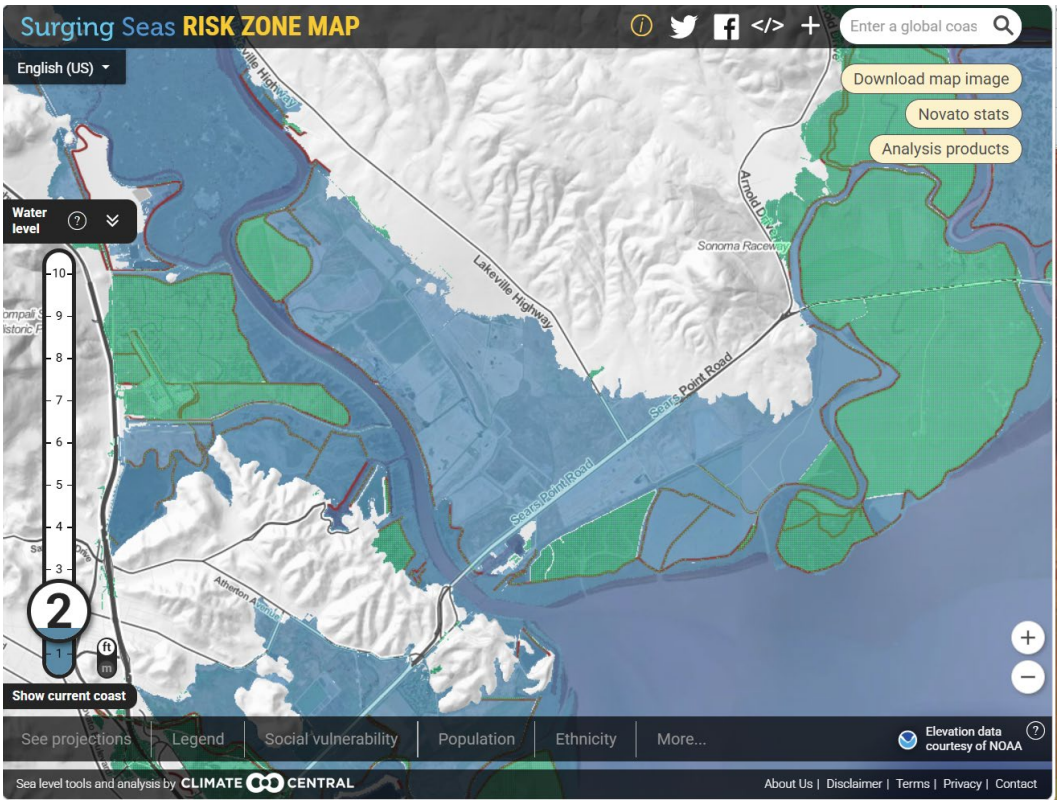
1) Corte Madera and San Rafael

2) The area around Novato Creek and highway 37 has flooded twice in the last 10 years (2017 and 2023), including closure for weeks. This resulted in a proposal to build a bridge spanning the area at risk, but construction is not until 2027 and beyond so this area remains at risk. There is a moderate likelihood of high-impact flooding in this area. Apparently Caltrans is readying for flooding in this area with construction of temporary flood walls. This may be sufficient to abate flooding of Highway 37, but probably not the surrounding fields. This area was highlighted as vulnerable in our 2016 report (https://hwy37.ucdavis.edu) and has flooded twice since then.



2) Novato Creek area of highway 37

3) One of the most vulnerable areas in the North San Francisco Bay is the area immediately east of Petaluma River, west of Lakeville Highway and north of highway 37. There is a combination of privately-owned and state-owned levees along the river protecting this area. The Road Ecology Center measured elevation of the levee in 2020 and found areas that were ~3 feet above “Mean Higher High Water” (MHHW). This term is the average of the highest high tide each day across some time period (e.g., 20 years). The additional sea level in this area from El Nino effects and stormwater runoff coming down Petaluma River means this levee has a chance of over-topping (water goes over the top of the levee). The top of this levee is pocked with animal burrows, is vegetated, is unmaintained and in many areas is only 3 feet wide. This is a high-probability, high-impact type of risk. Importantly, multiple modeling systems have independently predicted this as an area that could flood with 1 foot (Adapting to Rising Tides project), or 2 feet (UCD highway 37 study; Surging Seas Risk Zone Map) of SLR.

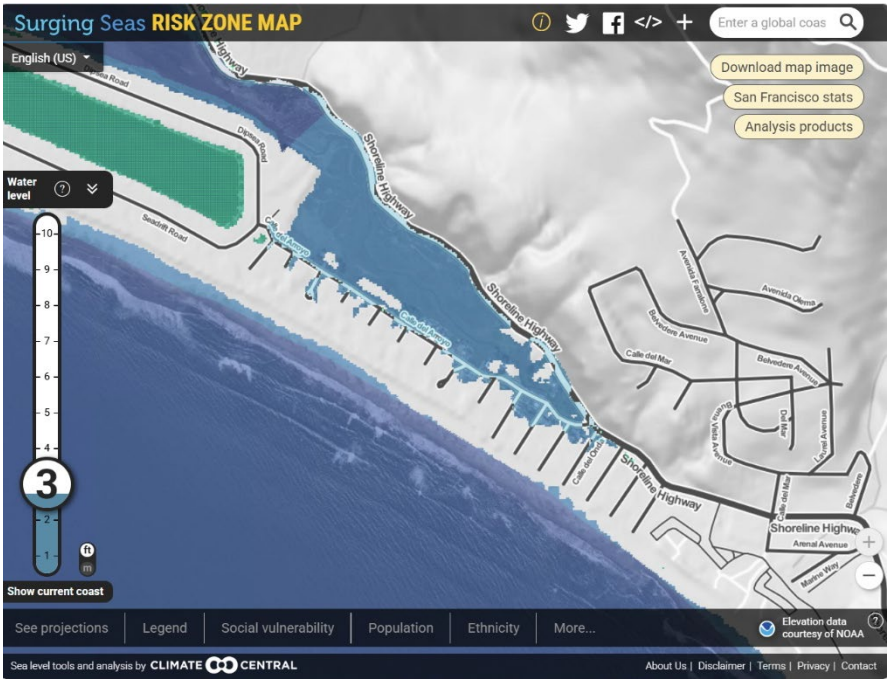


3) Area east of Petaluma River and north of highway 37

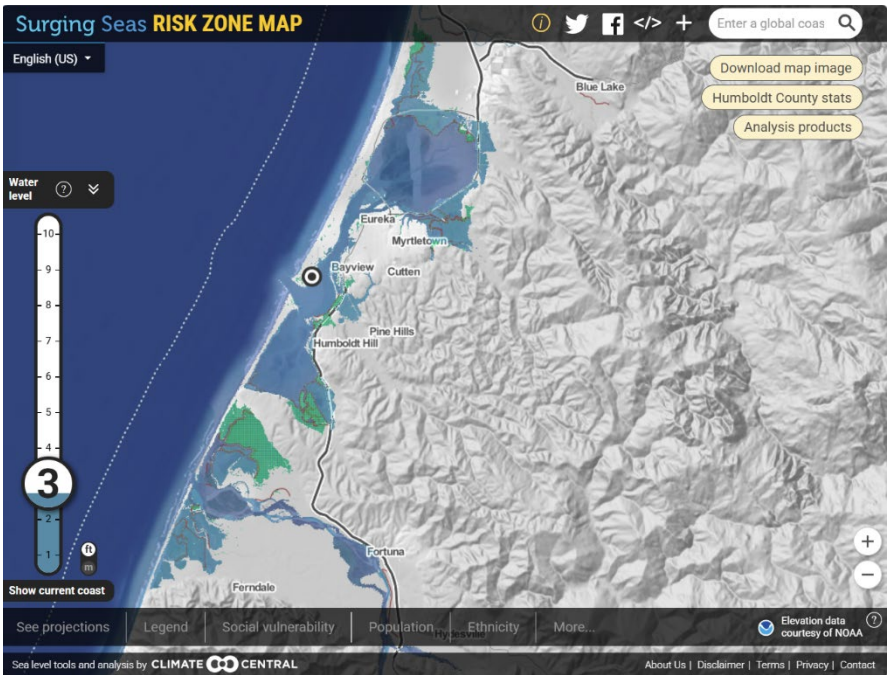
4) Tolay Creek Lagoon lies adjacent to Highway 37, just east of Sears Point (within orange circle on map). It is regularly a source of temporary flooding of Highway 37 (see photo on page 2 of this report). It is separated from a large parcel of agricultural land by a seldom-maintained levee. Flooding could be limited to Highway 37 adjacent to Tolay Lagoon, or with failure of the levee there could be flooding of the much larger agricultural area.



E. Stinson Beach beachfront, houses and local roads are all vulnerable to combinations of SLR, El Nino effects and heavy wave action. The primary access road to Stinson Beach is vulnerable to water elevations >2 feet. Highway 1 near the Bolinas lagoon is vulnerable to water elevations 3 feet or greater.



F. Within Humboldt Bay, local roads, fields, US101, and marshes are all vulnerable to flooding starting at 2 feet of sea elevation and up. Because the Bay is semi-enclosed, a combination of high tides, storm action pushing water into the Bay and stormwater runoff entering watersheds from the east could result in excessive water levels. This is a medium-probability, high-impact type of risk.



An important aspect of adaptive planning for climate change and sea level rise is the creation of maps of potential SLR exposure, which overlay future potential sea level and wave run-up hazard areas on existing infrastructure and natural features to assess SLR vulnerability (AECOM et al., 2011; BCDC, 2011). The public seems to find these maps of sea level rise and potential impacts, including inter active maps online, the most useful way to understand climate change effects (Schnotz, 2002; Retchless, 2014a,b; Monmonier, 2008; Kostelnick, 2013). Because there is considerable uncertainty in how much sea levels might rise, the types and costs of impacts, and when certain elevations and impacts will occur, many modeling and mapping projects attempt to display uncertainty and variability (Retchless, 2014b). At the same time, there is variation in how SLR maps are received by the public, which may be based upon scientific expertise, or trust in scientists (Retchless, 2014b).

Potential Impacts of Sea Level Rise

The most immediate impact of sea level rise is to newly flood lands that did not previously experience tidal or storm-based inundation. In addition, changes in wave height and run-up, as well as wave action on newly-eroded lands will impact shoreline areas as sea levels rise. In terms of California's low-lying towns, roads and surrounding lands, the most immediate and obvious impact will be to increase salinity and erosive pressure on beaches, bluffs, and marshes. As sea levels rise due to climate change and due to periodically extreme winters, more and more areas and infrastructure will be temporarily or permanently destroyed. Repair and replacement costs will mount from the current tens of millions into the hundreds of millions and eventually billions of dollars. In contrast, making shorelines more resilient now will cost a fraction of emergency repair and replacement costs, will reduce harm to people and ecosystems, and could contribute to a "restoration" economy rather than an emergency-response one.

Academic, USGS, and NOAA scientists are behind the accurate and carefully-constructed climate models. They have been urgently ringing the alarm bells as the impacts we face become clearer. They have invented ways to protect coastlines, move infrastructure, and protect communities. Now is the time to start basing government decision-making on science before we pass tipping points we can't come back from.

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