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Moss Landing Community

Coastal Climate Change Vulnerability Report

Photo: Don Debold

JUNE 2017

CENTRAL COAST WETLANDS GROUP

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Monterey County and the Community of Moss Landing

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Summary of Findings

This hazard evaluation is intended to provide a predictive chronology of future risks to benefit local coastal planning and foster discussions with state regulatory and funding agencies. Estimates of the extent of assets at risk of various climate hazards were made using best available regional data. This approach allows planners to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea level rise. The hazard maps provide projected hazard zones for each climate scenario for each of the three planning horizons. For clarity, this report focuses the hazard analysis on a subset of those scenarios, recommended by local and state experts.

- Most of the buildings (15) on the Moss Landing island, some buildings (8) within the Moss Landing Harbor, 3,896 acres of farm land, and 85,798 feet of road are located within the FEMA 100-year flood zone.
- The 2010 ESA Sea Level Rise risk models (excluding wave derived coastal flooding behind tide gates) project that 15 residential and 23 commercial properties and 12,483 feet of road are presently vulnerable to the hazards associated with Coastal Climate Change.
- The most critical protective structures within the Moss Landing area are the two tide gates that control tidal range within the lower Salinas Valley along the Old Salinas River and Tembladero Slough (Potrero Road tide gates) and Moro Cojo Slough (Moss Landing Road tide gates).
- By 2030, a total of 96 buildings are vulnerable to coastal climate impacts (excluding Coastal flooding behind tide gates, and erosion behind seawalls), 60 more than currently at risk (2010 vulnerability assessment).
- Ten buildings within the 2030 hazard area are located on Moss Landing Island, approximately 20 are located in the commercial district, and10 in the residential neighborhood off Potrero Road.
- The beach along the Moss Landing Island is projected to erode inland up to 70ft by 2030, placing the existing structures within the active wave impact zone.
- By 2030, erosion of the dunes south of Sandholdt Bridge will reduce the dune width to less than 200ft, decreasing the ability of the dunes to mitigate coastal flooding risks inland of the Potrero tide gate.
- There is a significant increase in the number of properties at risk of coastal climate change by 2060 and an almost complete loss of services on the island.

- Almost all the commercial district buildings and approximately half of the residences within the Monterey Dunes Colony fall within the 2060 combined hazard zone.
- By 2060 erosion of the dunes near Potrero road and near the Salinas River mouth are at risk of wave overtopping during storms, leading to ocean waves flowing into the Old Salinas River channel, bypassing the coastal flood protections provided by the tide gates.
- By 2100 the increased height of monthly tides becomes the driving hazard for Moss Landing adaptation planning.
- By 2100 much of the agriculture lands south of Moss Landing and west of Highway One will be vulnerable to frequent flooding due to further dune erosion and loss of water control structure functions.

1. Introduction

This report was funded by The Ocean Protection Council through the Local Coastal Program Sea Level Rise Adaptation Grant Program. This grant program is focused on updating Local Coastal Programs (LCPs), and other plans authorized under the Coastal Act[1] such as Port Master Plans, Long Range Development Plans and Public Works Plans (other Coastal Act authorized plans) to address sea-level rise and climate change impacts, recognizing them as fundamental planning documents for the California coast.

1.1 Project Goals

This project will achieve three key objectives to further regional planning for the inevitable impacts associated with sea-level rise (SLR) and the confounding effects of SLR on fluvial processes within the Moss Landing community. This project will:

1. Identify what critical coastal infrastructure may be compromised due to SLR and estimate when those risks may occur;
2. Identify how fluvial processes may increase flooding risk to coastal communities in the face of rising seas; and
3. Define appropriate response strategies for these risks and discuss with regional partners the programmatic and policy options that can be adopted within Community Plans, Hazard Mitigation Plans, and LCP updates.

The County of Monterey developed and adopted a Local Hazard Mitigation Plan in 2014. This plan works to "identify and profile natural hazards [storm surge, coastal erosion, earthquake, expansive soils, flood, and tsunami] and to lesser extent manmade hazards; assess vulnerability; set local hazard mitigation goals and strategy; and plan for future maintenance of the Local Hazard Mitigation Plan."[2] Sea level rise is not explicitly addressed by the plan, though increased intensity of coastal erosion and storm flooding due to sea level rise are discussed. The plan explores integrated mitigation strategies, which include actions to reduce vulnerability from erosion, flooding, and other natural and human hazards.

The Moss Landing Community Plan[3] discusses sea level rise and the importance of armoring the coastline in order to protect the harbor and its related coastal uses. This vulnerability report is intended to aid future planning to increase resiliency and provide greater detail on the risks to the Moss Landing

[1] State of California. *California Coastal Act of 1976*. http://www.coastal.ca.gov/coastact.pdf

[2] Monterey Multi-Jurisdictional Hazard Mitigation Plan, 2014, ch 2, pg 3

[3] Moss Landing Community Plan, Revised Draft 2014

area from coastal climate change during three future time horizons (2030, 2060 and 2100). Risks to properties were identified using the ESA PWA Monterey Bay Sea Level Rise Vulnerability Study[4] layers developed in 2014 using funding from the California Coastal Conservancy.

1.2 Study Area

Moss Landing is located on California's Central Coast along the Monterey Bay, in the Northern part of Monterey County. The study focuses within the residential, commercial and harbor district of the Moss Landing Community Plan Area and the surrounding low-lying agriculture and wetland areas, extending from the beaches, harbor and estuaries inland to the boundaries of the Coastal Zone (Figure 1). Specific neighborhoods discussed within this assessment are outlined in Section 2 and shown in Figure 2.

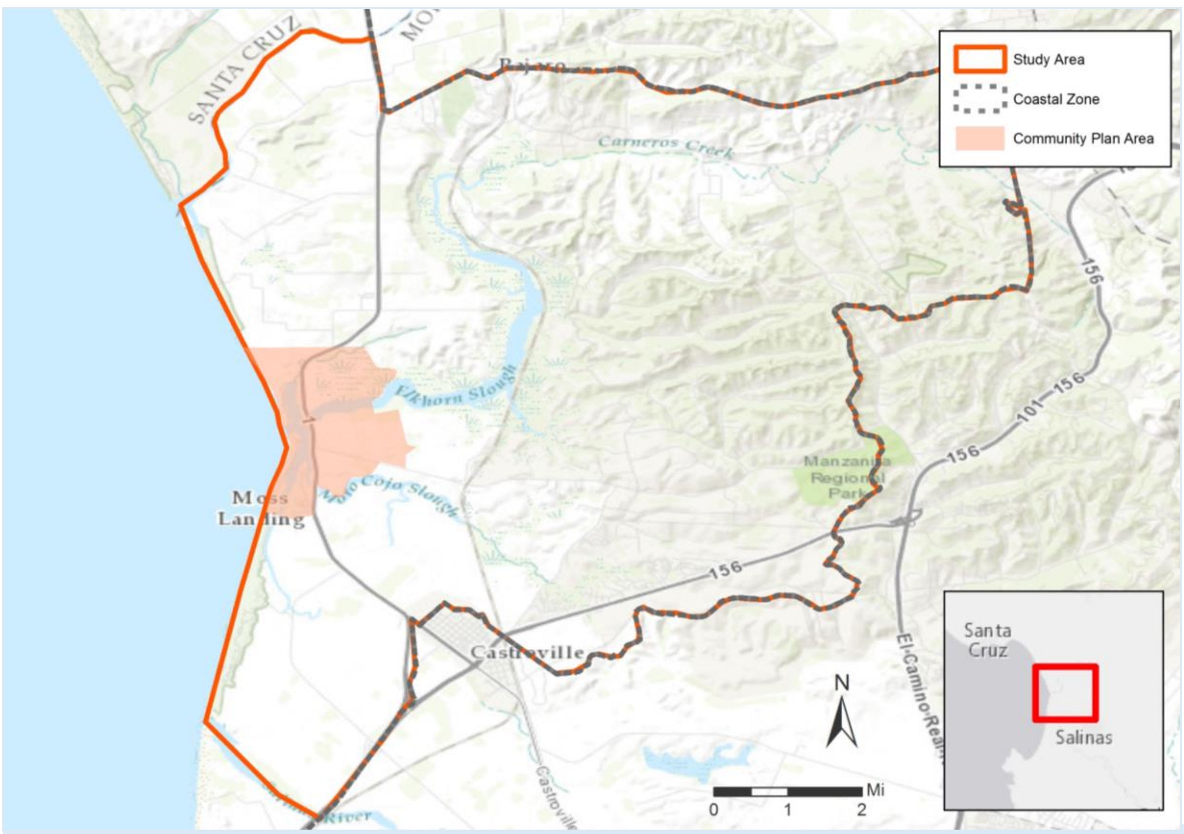

Figure 1. Moss Landing Study Area

[4] ESA PWA. 2014. *Monterey Bay Sea Level Rise Vulnerability Study: Technical Methods Report Monterey Bay Sea Level Rise Vulnerability Study*. Prepared for The Monterey Bay Sanctuary Foundation, ESA PWA project number D211906.00, June 16, 2014

2. Community Profile

2.1 Local Setting and Climate

Moss Landing has a mild climate, with average monthly high temperatures ranging from low 60s to low 70s, and average monthly lows ranging from high 30s to low 50s. Moss Landing is often foggy in the summertime, due to the temperature differential between land and sea.

The Moss Landing community is surrounded by water—the ocean, Elkhorn Slough, Moro Cojo Slough, and the nearby Salinas River encircle this historical fishing community. This proximity to the ocean leaves Moss Landing vulnerable to periodic flooding, now and due to climate change, more so in the future. Storm events have impacted the community in the past; including the 1995 flood and the 1982 and 1998 el Nino events. Each of these climatic events has damage infrastructure and properties.

Moss Landing is a small fishing village with restaurants, antique stores, and galleries, best known for its working harbor and proximity to Elkhorn Slough and the productive farmlands of the Salinas Valley. Moss Landing hosts the annual Antique Street Fair and other cultural events and supports the research and educational endeavors of the Monterey Bay Aquarium Research Institute and Moss Landing Marine Laboratories. The seven neighborhoods defined within the Moss landing Community Plan along with the one additonal neighborhood outside of the Community Planning Area (Moss Landing Dunes Colony) are described below.

Island

This mixed-use district is located along the Sandholdt Road separated from the rest of Moss landing by the Old Salinas River Channel. The Sandholdt Bridge connects the harbor to the Island. This area includes the Monterey Bay Aquarium Research Institute (MBARI), the Moss Landing Marine Labs (MLML) Shore Lab, Del Norte Building and Marine Operations, and Phil's Fish Market. Along the east side of this sand spit are numerous harbor facilities.

Village

The Moss Landing Village neighborhood parallels Moss Landing Rd and is Moss Landing's main commercial area. A number of restaurants, antique shops, and other small businesses are located here, as well as the post office and North Monterey County Unified School District. Moss Landing Marine Labs main campus is also located in this area.

Harbor North and South

The Moss Landing Harbor has parking and other harbor and beach access facilities. The harbor supports commercial fishing and recreational boating as well as restaurants. The Jetty Road sand spit is located in along the northeast side of the harbor.

Heights

This residential neighborhood is located along Potrero Road and Pieri Court on the south side of the Moss Landing Community Plan Area.

Elkhorn

This area is primarily wetland habitat that borders Elkhorn Slough and encompasses the Moss Landing State Wildlife Area.

Dolan

This area is primarily zoned for heavy industry and contains the Moss Landing Power Plant.

Dunes Colony

The Monterey Dunes Colony is a residential community located off Monterey Dunes Way south of Moss Landing. This neighborhood falls outside of the Moss Landing Community Plan Area, however.

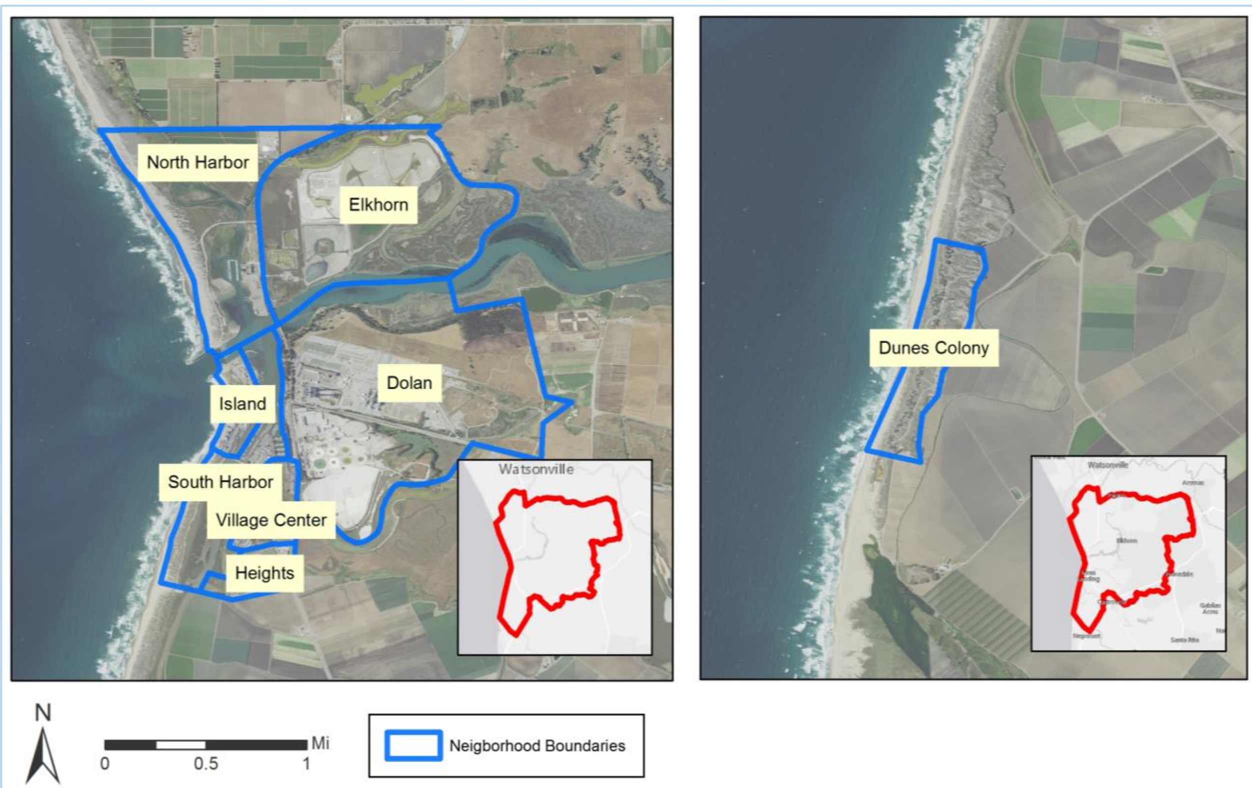

Figure 2. Moss Landing Neighborhoods

2.2 Demographics

The census-designated place of Moss Landing has a population of 200 people (ACS 2014 estimate). Of the 200 people, 145 identify as white and 55 identify their race as other; 163 identify as Hispanic or Latino. The median household income is $30,500, the mean household income is $47,653, and 34.5% of the civilian workforce is unemployed, with 12.5% of people under the poverty line. 80% of people have a high school diploma, and 4.5% have a bachelor's degree or higher.[5]

2.3 Community Resources and Assets

Land Use

Important Facilities: Moss Landing features two important research facilities, Monterey Bay Aquarium Research Institute (MBARI) and Moss Landing Marine Laboratories (MLML), both focused on oceanographic and marine research and education. Moss Landing is also home to a natural gas-powered electric generation plant, which provides electrical power to the Central Coast.[6] The Moss Landing Post Office is located in Moss Landing village.

Monterey Dunes Colony*:* The Dunes Colony features 120 two, three, and four-bedroom vacation homes stretched out over a mile of beach front property. The Dunes Colony is bordered by Salinas River State Beach to the north and south.

Accommodations, Food, and Shopping*:* Moss Landing has one Bed & Breakfast, Captain's Inn, as well as 4 private vacation rentals and a campground. There are 14 shops, and 15 restaurants, cafes, and markets.[7]

Emergency Services: Moss Landing Harbor provides berths for Coast Guard and California Dept. of Fish and Wildlife boats.

Farmland*:* Moss Landing community is surrounded by thousands of acres of productive farmland, growing artichokes, cauliflower, broccoli, turnips, squash and brussel sprouts.

Recreation and Public Access

Beaches, Parks, and Reserves: Moss Landing State Beach, Salinas River State Beach (part of which is designated as the Salinas River Dunes Natural Preserve), and Zmudowski State Beach Park offer great places for surfing, horseback riding, surf fishing, windsurfing, hiking, and wildlife-watching.
The Elkhorn Slough National Estuarine Research Reserve, the Elkhorn Slough State Marine Reserve, and the Moss Landing State Wildlife Area (limited recreation access), encapsulate Elkhorn Slough and its many surrounding wetlands, while also providing more than five miles of hiking and boardwalk trails,

[5] United States Census Bureau, http://factfinder2.census.gov
[6] Moss Landing Community Plan, Revised Draft 2014
[7] Moss Landing Chamber of Commerce, http://www.mosslandingchamber.com/directory.html

and a visitor center with restrooms and a paved overlook road. The slough is also accessible by kayak or small boat from the harbor, allowing up-close viewing of the incredible biodiversity.

The Monterey Bay Marine Sanctuary Scenic Trail runs through Moss Landing, helping link Santa Cruz and Monterey County coastal access infrastructure.

Moss Landing Harbor*:* The Moss Landing Harbor is the number one commercial fishing harbor in the Monterey Bay with 600+ slips for recreational boaters and commercial vessels. Partnering with marine research and education, the Moss Landing Harbor District (MLHD) provides full public access to the environment. Designated as a year-round port of safe refuge, Moss Landing Harbor provides safe, reliable marine refuge and services to boating members of this community.

Coastal Access and Public Parking: Boats within the harbor offer tours of Elkhorn Slough and the Monterey Bay National Marine Sanctuary to observe local wildlife. There are public parking lots and street parking on Jetty Road, just off of Highway 1, to provide easy access to the beach. There are parking lots near Kayak Connections for kayakers, and there are parking lots around the harbor providing access to the Slough and the ocean. Access and parking to Salinas River State Beach is provided at the ends of Sandholdt, Potrero and Molera roads.

Transportation

Highway 1*:* Highway 1 runs through Moss Landing with a bridge crossing Elkhorn Slough.

Rail: The rail line transects the Moss Landing study area passing through Elkhorn and Moro Cojo sloughs. The rail line is operated daily by Southern Pacific for both commercial and passenger service.

Bridges: There are a number of bridges and roads that overpass the complex network of creek and wetland features within Moss Landing.

Natural Resources

Wetlands: Elkhorn Slough's tidal salt marsh provides critical habitats for many species, including more than 135 species of aquatic birds, 550 species of marine invertebrates, and 102 fish species, as well as sea otters, sea lions, and harbor seals. Surrounding wetlands including the Moro Cojo Slough and Old Salinas River provide important habitats for threatened species and flood attenuation during winter storms.

Dunes*:* The beach dunes along Moss Landing State Beach and Salinas River State Beach provide important habitat for many native plants and animals, including the western snowy plover, the white-tailed kite, western fence lizard, beach wild rye, beach bur, yellow sand verbena, and many more species.

Protected Habitats: Monterey Bay National Marine Sanctuary, Elkhorn Slough State Marine Conservation Area, Elkhorn Slough State Marine Reserve, Elkhorn Slough National Estuarine Research

Reserve, Moss Landing State Wildlife Area, Moro Cojo State Marine Reserve, Salinas River Dunes Natural Preserve, and California State Beaches support special status species and their habitats.

Water and Utility Infrastructure

Tide Gates: There are two tide gates in place to help reduce tidal range within the Old Salinas and Moro Cojo sloughs. These structures restrict tidal flooding to large areas of the southern Moss Landing study area but also inadvertently restrict river discharge during large winter storms.

Pump Station*:* There is a wastewater pump station located along Moss Landing Road across the street from the North Monterey County School District office.

2.4 Historical Events

Moss Landing and nearby farmlands are vulnerable to both river and ocean flooding. Monterey County Water Resources Agency describes recent flooding on their website[8] and outlined below in Table 1. The 1995 March floods resulted in County-wide flooding to private property resulting in damage to 1,500 homes and 110 businesses. In Castroville 312 residences and 38 businesses were damaged and 1,320 residents were evacuated. The County describes a second flood event in February 1998 events as;

> *"a series of El Niño winter storms which hit various parts of California, and particularly Monterey County. Close timing of the rainfall events contributed to intense flooding, in that heavy rain would continually hit ground that was still saturated from the previous rain. An estimated 50 roads and highways were closed or restricted, in most cases due to washouts, landslides, and mudslides. Several communities were evacuated, particularly the entire town of Pajaro near Watsonville, all residents of the Sherwood Lake Mobile Home Park near Carr Lake in Salinas, and portions of Bolsa Knolls and Toro Estates. Drinking water quality warnings remained in effect for certain areas for some time afterward. By the end of the first week of February, at least 6,600 homes and businesses had been without power for varying periods of time."*

County-wide, losses resulting from the 1998 event are estimated at over $38 million, with agriculture-related losses totaling over $7 million and damaging 29,000 acres of crops. A similar increase in tidal flooding occurred in 2014 after the failure of the Moro Cojo tide gates which allowed the estuary to fill slowly over numerous months with saltwater (tidal range did not appear to increase). Portions of the Moro Cojo Slough were inundated with salt water above the habitats normal range, leading to the dieback of fringing brackish and freshwater plant communities.

[8] Monterey County Water Resources Agency. Historical Flooding. http://www.mcwra.co.monterey.ca.us/floodplain_management/historical_flooding.php

Table 1. Major Floods in Moss Landing and Northern Monterey County, 1911 to Present
(Sources: Monterey County and California Dept. Water Resources)

DATE	DESCRIPTION OF DAMAGE
March 1911	More than 2,000 acres of farmland destroyed along Salinas River, electric light plant, pumping plant, oil tanks half submerged, buildings along river underwater, debris.
January 1914	Bridge damage, some bridges carried away, torrential rains.
February 1938	Salinas River flooded, damaged bridges, crops, and roads.
Winter 1940-41	Closed roads, washed out piers and foundations, flooded streets, most rainfall for any season since 1890.
February 1945	Lots of rain over 36 hours during an extreme dry spell, little damage.
January 1966	32,000 acres of farmland inundated along the Salinas River, estimated $6,572,000 in damage.
January & February 1969	2 successive floods of the Salinas River, lots of damage throughout the county
March 1995	Damage all over the county, mass evacuations throughout, including Moss Landing
February 1998	El Niño winter storms hit, rain and saturated ground, land and mudslides
March 2011	Tsunami, maximum amplitude of 2 meters in the area, Moss Landing damages: $1,020,000
December 2014	Flooding in lower Salinas Valley due to localized rain and flooding in the Gabilan Watershed. Costs to the agriculture industry estimated at more than $1,500,000
Winter 2017	Numerous winter storms hit, dune erosion, rain, saturated ground and flooding, land and mudslides

2.5 Coastal Protection Infrastructure and Management

There are a number of coastal protection structures in Moss Landing that reduce risks of coastal and fluvial erosion as well as tidal, storm, and fluvial flooding (Table 2). Unlike much of the Monterey Bay coastline, most coastal protective structures within Moss Landing are designed to maintain harbor functions and limit inland tidal flooding of agricultural areas.

Table 2. Inventory of Existing Coastal Protection and Water Control Structures in Moss Landing

STRUCTURE LOCATION	TYPE OF STRUCTURE
Rip-rap in front of MLML Aquaculture Center	Rip-rap seawall
Wall in front of MBARI Building	Concrete wall and building wave barrier
Wall in front of MBARI Office Building	Concrete wall and building wave barrier
Hip Wall in front of Phil's Fish Market	Concrete wall
Hip Wall in front of Del Norte	Concrete wall
Moss Landing Harbor Jetties	Rip-rap jetties
Highway 1 Bridge over Elkhorn Slough	Bridge on pilings
Highway 1 overpass above Moro Cojo Slough	Box culvert
Elkhorn road overpass above Elkhorn Slough	Multiple box culverts
Rail road bridge over Elkhorn slough	Wooden Rail bridge
Rail road bridge over Moro Cojo slough	Wooden Rail bridge
Moss Landing Road Culverts	Cylindrical culverts with tide gates
Sandholdt Bridge	Concrete bridge with pilings
Potrero Tide Gates	Cylindrical and box culverts with tide gates
Molera Road Bridge over Tembladero Slough	Concrete bridge with pilings
Dunes Colony Road culverts	Cylindrical culverts
Highway 1 Bridge over Tembladero Slough	Concrete bridge with pilings
Rip-rap in front of ag field at Salinas River Mouth	Rip-rap pile along river channel
Culverts under Castroville Blvd	Multiple box culverts

Rip rap in front of the MLML Shorelab

Remnant concrete structure in front of MLML Shorelab

Hip wall in front of MBARI

Figure 3. Coastal armoring structures of various conditions along Moss Landing shoreline
(Photos: Sarah Stoner-Duncan)

Moss Landing Shoreline Protection Structures

Approximately 1,300 feet of coastal armoring including hip-walls, rip rap, and dune building/restoration, have been constructed along the beach south of the harbor entrance (on Moss Landing "Island") to protect adjacent buildings including the Moss Landing Marine Labs (MLML) Shore Lab and Monterey Bay Aquarium Research Institute (MBARI) (Figure 3). These structures are of various ages, conditions and levels of service. The MBARI sea wall is in excellent condition and the building is designed to be resilient to wave run-up damage that may occur during large storms. The northern MBARI building is protected by a dune enhancement and restoration project that has increased the height of the dunes between the ocean edge and the property. MBARI and MLML Del Norte are further protected by hip-walls that run between the back edge of the dunes and the parking lots of these properties. The Del Norte property is also protected by a dune enhancement and restoration project that has elevated the dunes in front of this property by approximately four feet. The Moss Landing Marine Labs Shore Lab is located directly south of the MBARI facility. This property's seaward edge is maintained by a remnant concrete and steel pad from an old pier that has been destroyed. Rip-rap and concrete rubble of poor condition further protects this property from erosion. As much as 25 feet of the property behind the rip-rap is no longer in use.

Harbor Shoreline Structures

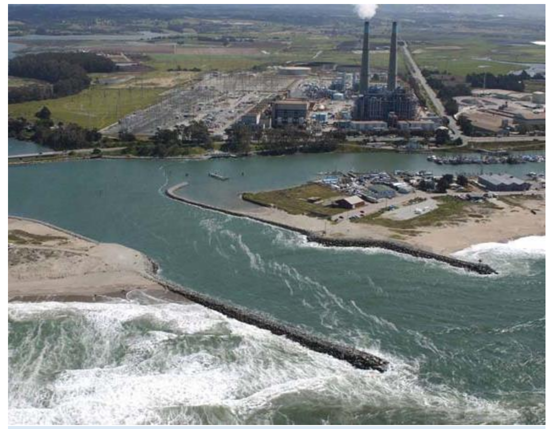

Figure 4. Moss Landing Harbor levees
(Coastal Records Project, Kenneth & Gabrielle Adelman)

Much of the Moss Landing Harbor is developed for commercial and recreational boating and is comprised of a mix of rip-rap and concrete sea walls. A large amount of harbor related infrastructure was built within the footprint of the historical Old Salinas River. The Harbor entrance is maintained by two large rock jetties that reach more than 1,500 feet out from the main harbor channel into the open Monterey Bay (Figure 4). The harbor mouth and main harbor channel are dredged periodically to maintain operational depth. While the jetties remain in good condition, the sand behind the inland end of structures has eroded by tidal eddies that scour sand and deposit those sediments elsewhere (in the north harbor area). Most of the 2.5 km of the south harbor waterfront is man-made and or hardened with rip-rap or concrete. Only one quarter (0.5km) of the north harbor waterfront is protected or hardened.

Water Control Structures

There are 3 tide gates and 26 culverts that manage river discharges and tidal exchange within this area (Figure 5). Many of these structures are in disrepair, often exacerbated by a complex network of agency ownership and management agreements. Much of this infrastructure was designed to function under static sea level, rain fall and river discharge conditions and may be undersized or unable to function properly under predicted future conditions. Two of the tide gates (Moss Landing Road and Potrero Road) protect the Salinas Valley, South of the harbor from flooding during high tides and ocean storms.

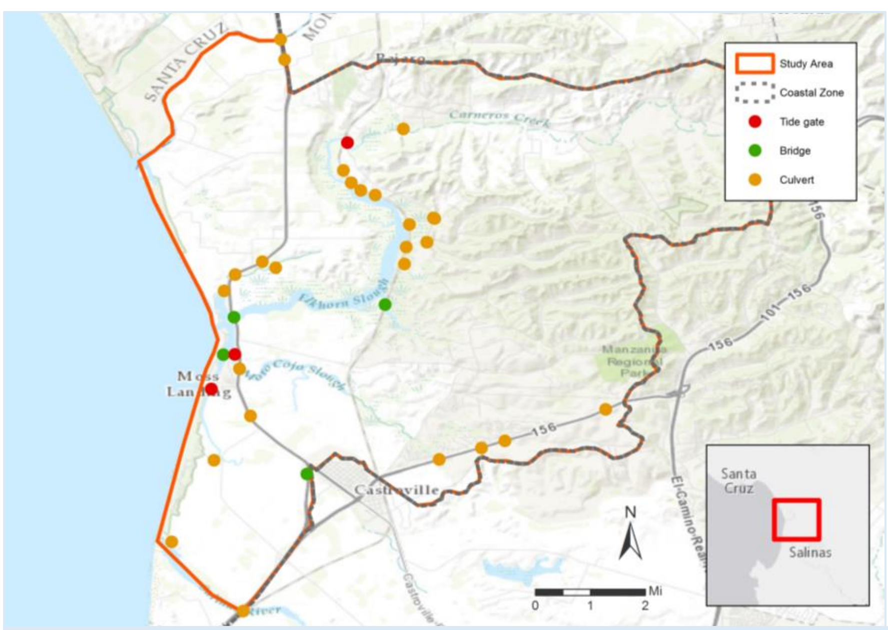

Figure 5. Moss Landing Area water control infrastructure and bridges

Sand Dunes

To the south, the residential properties within the Monterey Dunes Colony rely on native dune restoration and erosion management to protect structures from wave impacts. The dunes also protect the low-lying Salinas Valley from wave induced flooding.

Active Management

Much of the vast historical Salinas River estuary has been “reclaimed” for grazing, agriculture, development, the harbor and other uses. Reclamation efforts frequently included digging drainage ditches to drain flood waters from the marsh edges and the construction of berms along the main channels to keep tide and flood waters from once again flooding these properties. Large portions of these reclaimed lands are no longer useful for agriculture or other purposes because of high ground water and salt accumulation in the soils. The berms that protected these properties have fallen into disrepair and in many locations, have been removed or compromised leading to restored flooding of these properties. The farming lands along the Old Salinas River (OSR) and Tembladero Slough/Gabilan drainage have remained as farmland because of their high productivity, lower (but still significant) salt accumulation within the soils, and relative protections provided by the tide gates. The tide gates at Potrero and Moss Landing roads restrict tidal flooding and salt water intrusion. The OSR/Tembladero has not been flooded (because of the tide gates) by the increased tidal range associated with the opening of the harbor mouth. Much of the Reclamation Ditch is hardened with rip-rap or concrete spoils to reduce channel bank erosion.[9]

[9] The Elkhorn Slough National Estuary Research Reserve has completed a nine-year planning process to prioritize future management of the Elkhorn Slough including the future threats of SLR and climate change, and therefore was not a focus for this vulnerability assessment. Elkhorn Slough Tidal Wetland Project (TWP) characterized four large-scale alternatives designed to decrease tidal scour and associated negative impacts resulting from this artificial mouth. The future implications of Sea Level Rise were reviewed extensively within this planning process. Specific long-term management and SLR adaptation recommendations for the Elkhorn Slough are available within the documents produced by the TWP http://www.elkhornslough.org/tidalwetlandproject/.

3. Projecting Impacts

3.1 Disclaimer: Hazard Mapping and Vulnerability Assessment

Funding Agencies

The hazard GIS layers used in this analysis were created with funding from The State Coastal Conservancy and this Vulnerability Analysis was prepared with funding from the Ocean Protection Council. The results and recommendations within this planning document does not necessarily represent the views of the funding agencies, its respective officers, agents and employees, subcontractors, or the State of California. The funding agencies, the State of California, and their respective officers, employees, agents, contractors, and subcontractors make no warranty, express or implied, and assume no responsibility or liability, for the results of any actions taken or other information developed based on this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. These study results are being made available for informational purposes only and have not been approved or disapproved by the funding agencies, nor has the funding agencies passed upon the accuracy, currency, completeness, or adequacy of the information in this report. Users of this information agree by their use to hold blameless each of the funding agencies, study participants and authors for any liability associated with its use in any form.

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3.2 Coastal Hazard Processes

The ESA coastal hazard modeling and mapping effort[10] led to a set of common maps that integrate the multiple coastal hazards projected for each community (i.e. hazards of coastal climate change). There is however a benefit to evaluating each hazard (or coastal process) separately and presented below. Two important limitations of the original hazard maps were addressed within this focus effort for Moss Landing. ESA was contracted for this project to model the impacts of flooding from the combined effects of rising seas and changes in rainfall leading to an increase in winter stream flows. CCWG staff post processed 2030 hazard layers to account for reductions in potential hazards provided by current coastal protection infrastructure (see section 3.3). This refinement of coastal hazard mapping helped to better understand the future risks Moss Landing may face for each coastal hazard process.

It is understood that each modeled coastal process will impact various coastal resources and structures differently. This report evaluates the risks to infrastructure from each coastal hazard for each time horizon. This analysis helps to link risks with appropriate adaptation alternatives. The following is a description of the hazard zone maps that were used for this analysis. For more information on the coastal processes and the methodology used to create the hazard zones please see the Monterey Bay SLR Vulnerability Assessment Technical Methods Report.[10]

FEMA

FEMA flood hazard maps are used by the National Flood Insurance Program and present coastal and fluvial flood hazards. These maps only assess existing hazards and do not consider future erosion or projected sea level rise and therefore, are believed to underestimate future coastal flood hazards. A recent enhancement of FEMA flood maps has been underway for the California Coastline. FEMA describes the effort as, "Region IX is initiating flood studies/mapping projects in coastal areas as a result of Congressional appropriations for Flood Hazard Mapping under Risk MAP . These efforts will address

[10] ESA PWA. 2014. *Monterey Bay Sea Level Rise Vulnerability Assessment Technical Methods Report*

gaps in required engineering and mapping for high flood risk areas impacted by coastal flooding. Cumulatively, these flood studies/mapping projects are being referred to as the California Coastal Analysis and Mapping Project (CCAMP)." Our review of initial map outputs suggests that the new analysis does account for coastal storm flooding impacts to the Salinas Valley. Once these maps are finalized, overlay of these hazard areas with the hazard layers used for this Moss Landing study would aid local agency understanding of how various hazards are interpreted and how current protective infrastructures are accounted for within the FEMA coastal flood maps.

Combined Hazards

CCWG merged the coastal hazard layers (for the specific scenarios[11] as modified to account for structures) to create a new combined hazard layer for each planning horizon (2030, 2060 and 2100). These merged layers represent the combined vulnerability zone for "Coastal Climate Change" for each time horizon. Projections of the combined hazards of Coastal Climate Change are intended to help estimate the cumulative effects on the community and help identify areas where revised building guidelines or other adaptation strategies may be appropriate. Combined hazards however, do not provide municipal staff with the necessary information to select specific structural adaptation responses. Therefore, this study also evaluates the risks associated with each individual coastal hazard.

Rising Tides

These hazard zones show the area and depth of inundation caused simply by rising tide and ground water levels (not considering storms, erosion, or river discharge). The water level mapped in these inundation areas is the Extreme Monthly High Water (EMHW) level, which is the high water level reached approximately once a month. There are two types of inundation areas: (1) areas that are clearly connected over the existing digital elevation through low topography, (2) and other low-lying areas that don't have an apparent connection, as indicated by the digital elevation model, but are low-lying and flood prone from groundwater levels and any connections (culverts, storm drains and underpasses) that are not captured by the digital elevation model. This difference is captured in the "Connection" attribute (either "connected to ocean over topography" or "connectivity uncertain") in each Rising Tides dataset. These zones do not, however, consider coastal erosion or wave overtopping, which may change the extent and depth of regular tidal flooding in the future. Projected risks from rising tides lead to reoccurring flooding hazards during monthly high tide events.

Coastal Storm Flooding

These hazard zones depict the predicted flooding caused by future coastal storms. The processes that drive these hazards include (1) storm surge (a rise in the ocean water level caused by waves and pressure changes during a storm), (2) wave overtopping (waves running up over the beach and flowing into low-lying areas, calculated using the maximum predicted wave conditions), and (3) additional flooding caused when rising sea level exacerbate storm surge and wave overtopping. These hazard zones also take into account areas that are projected to erode, sometimes leading to additional flooding through new hydraulic connections between the ocean and low-lying areas. Storm flood risks represent

[11] See the 2017 Santa Cruz County Coastal Climate Change Vulnerability Report for the discussion on scenario selection

periodic wave impact and flooding. These hazard zones DO NOT consider upland fluvial (river) flooding and local rain/run-off drainage, which likely play a large part in coastal flooding, especially around coastal confluences where creeks meet the ocean (analyzed separately for the Moss Landing area).

Dune Erosion

These layers represent future dune (sandy beach) erosion hazard zones, incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise and (in the case of the storm erosion hazard zones) the potential erosion impact of a large storm wave event. The inland extent of the hazard zones represents projections of the future crest of the dunes for a given sea level rise scenario and planning horizon. Erosion can lead to a complete loss of habitat, infrastructure and/or use of properties.

Fluvial Flooding

A river flooding vulnerability analysis was completed specifically for this study to evaluate the cumulative impacts of rising seas and future changes in fluvial discharge within the Gabilan Watershed. The ESA modeling team expanded hydrologic models of the Gabilan watershed provided by the County to estimate discharge rates under future climate scenarios. The fluvial model estimates localized flooding along the Reclamation Ditch/Gabilan Creek when discharge is restricted behind the Potrero tide gates during high tides. The model results are presented here and the methodology is described within the separate Fluvial Report by ESA[12].

3.3 Scenario Selection and Hazards

The California Coastal Commission guidance document[13] recommends all communities evaluate the impacts from sea level rise on various land uses. The guidance recommends using a method called "scenario-based analysis" (described in Chapter 3 of the Guidance). Since sea level rise projections are not exact, but rather presented in ranges, scenario-based planning includes examining the consequences of multiple rates of sea level rise, plus extreme water levels from storms and El Niño events. As recommended

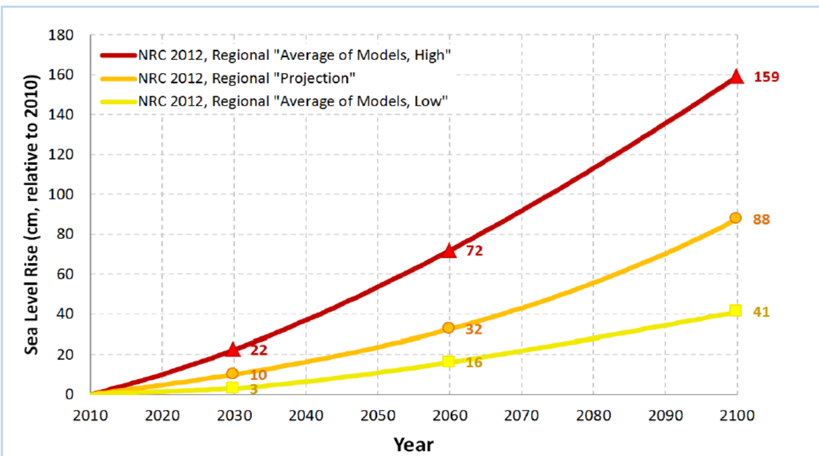


Figure 6. SLR Scenarios Sea Level Rise scenarios for each time horizon. (Figure source: ESA 2014)

[12] ESA. 2016. *Climate Change Impacts to Combined Fluvial and Coastal Hazards*. May 13, 2016.

[13] California Coastal Commission. 2015. *California Coastal Commission Sea Level Rise Policy Guidance: Interpretative Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits.* Adopted August 12, 2015.

in the Coastal Commission guidance, this report uses sea level rise projections outlined in the 2012 NRC Report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*[14] (Figure 6). The goal of scenario-based analysis for sea level rise is to understand where and at what point sea level rise and the combination of sea level rise and storms, pose risks to coastal resources or threaten the health and safety of developed and natural areas. This approach allows planners to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea level rise. The climate vulnerability maps used for this study identify hazard zones for each climate scenario for each of the three planning horizons. For clarity, this report focuses the hazard analysis on a subset of those scenarios, recommended by local and state experts (Table 3).

The Coastal Commission recommends all communities evaluate the impacts of the highest water level conditions that are projected to occur in the planning area. Local governments may also consider including higher scenarios (such as a 6.6 ft. (2m) Scenario) where severe impacts to Coastal Act resources and development could occur from sea level rise. In addition to evaluating the worst-case scenario, planners need to understand the minimum amount of sea level rise that may cause impacts for their community, and how these impacts may change over time, with different amounts of sea level rise.

Table 3. Coastal Hazard Scenarios selected for analysis

TIME HORIZON	EMISSIONS SCENARIO	SLR	NOTES
2030	med	0.3 ft (10 cm)	Erosion projection: Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm)
2060	high	2.4 ft (72 cm)	Erosion projection: Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm) Future erosion scenario: Increased storminess (doubling of El Niño storm impacts in a decade)
2100	high	5.2 ft (159 cm)	Erosion projection: Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm) Future erosion scenario: Increased storminess (doubling of El Niño storm impacts in a decade)

[14] National Research Council (NRC). 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Report by the Committee on Sea Level Rise in California, Oregon, and Washington. National Academies Press, Washington, DC. 250 pp.

3.4 Assumptions and Modifications to ESA Hazard models

Coastal Armoring and Tide Gates

The ESA coastal hazard projections do not account for the protections that existing water control structures and coastal armoring provide to reduce coastal erosion and coastal flooding (both storm flooding and rising tides). Because existing armoring and tide gate functions are not accounted for, the areas identified as vulnerable by the original coastal erosion ESA GIS layers overestimate future erosion, coastal storm flooding, and rising tides hazard zones (as recognized within the ESA supporting documentation). To address this issue, a GIS layer of existing coastal armoring was referenced to identify areas where some level of protection currently exists.[15]

To account for the protections provided by coastal armor and tide gates, assets located behind those structures were removed from the 2010 and 2030 erosion, coastal storm flooding and rising tides vulnerability analysis. In many cases, properties were reclassified as “protected” from coastal hazards by recognizing the protections those structures provided. Coastal flooding layers accounted for the height of coastal structures (hip walls etc.) and predicted the potential for wave overtopping and flooding that may occur with those structures in place. Some structures were therefore identified as protected from coastal erosion and vulnerable to coastal flooding.

Because the life span of coastal infrastructure is limited, this vulnerability analysis assumes that all existing coastal protection and tide gate infrastructure will fail and need to be removed, replaced or significantly redesigned at some point between 2030 and 2060. Once these structures fail, erosion will accelerate and quickly meet projected inland migration rates (as documented at Stilwell Hall, Fort Ord) unless protective measures are implemented. Therefore, the vulnerability analysis for the 2060 and 2100 planning horizons assumes that current coastal armoring and tide gates will no longer function and that the modeled hazard zone layers provided by the ESA technical team fully represent future hazards for these time horizons.

3.5 Assets Used in Analysis

For this study, community infrastructure and assets were divided into five categories that include: Land Use and Buildings; Water and Utility Infrastructure; Parks, Recreation and Public Access; Transportation; and Natural Resources. GIS layers were obtained from County and State data repositories, or created by Central Coast Wetlands Group. Assets that fell outside of the planning area were not included in this report. Several data layers that were intended to be used in this analysis were not available (Table 4).

[15] California Coastal Commission. 2014. *GIS layer of existing coastal armor structures in Santa Cruz County.*

Table 4. List of Assets Used in Analysis

ASSET CATEGORY	ASSET	STATUS OF ASSET IN ANALYSIS
Land Use	Building footprints	Analyzed
	Commercial, Residential, Public, Visitor Serving	Analyzed
	Emergency Services: Hospitals, Fire, Police	Analyzed
	Schools, Libraries, Community Centers, etc.	Analyzed
	Parcels	Not used in analysis[16]
	Farmland	Analyzed
	Military	None in Planning Area
	Historical and Cultural Buildings	Not used in analysis[17]
Water and Utilities Infrastructure	Sewer Structures & Conduits	Unable to obtain data
	Water Main Lines	Unable to obtain for analysis
	Gas	Unable to obtain for analysis
	Storm Drain Structures & Conduits	Analyzed (partial data set)
	Tide gates and Culverts	Analyzed
Parks, Recreation, and Public Access	Coastal Access Points	Analyzed
	Parks	Analyzed
	Beaches	Analyzed
	Coastal Trail	Analyzed
	Coastal Access Parking	Analyzed
Transportation	Roads	Analyzed
	Rail	Analyzed
	Bridges	Not used in analysis
	Tunnels	None in Planning Area
Natural Resources	Wetlands	Analyzed
	Critical Habitat	Analyzed
	Dunes	Analyzed

[16] Building foot print layers were used instead of parcels maps to better project future structural vulnerabilities.
[17] The data are available but not reported within this document.

4. Combined Impacts of Coastal Climate Change

4.1 Background

Previous storm driven damage to the Moss Landing shoreline and low-lying areas was derived from the combination of several different types of impact. Waves damage buildings through blunt force impact. Waves overtop dunes and sea walls leading to localized or extensive flooding of low lying areas. Flooding is often exacerbated by storm drains and tide gates that impede drainage of those waters to the ocean. Future risks of flooding and wave impact damage will be magnified as higher local sea levels and greater wave heights combine during winter storms with higher river discharges. Greater wave impact intensity will cause greater damage to coastal structures and wave heights will extend risks of damage further inland as waves overtop coastal structures more intensively and propagate further up the Moss Landing Harbor, Elkhorn Slough and Old Salinas River. These cumulative threats are termed within this document as the risks of "Coastal Climate Change."[18]

4.2 Existing Vulnerabilities

FEMA

Federal Emergency Management Agency (FEMA) has produced flood hazard maps that identify several portions of the Moss Landing Community as vulnerable to river flooding during a 100-year flood event (based on historical rainfall data, new maps are expected to be available soon). FEMA identifies most of the buildings (15) on the Moss Landing Island, some buildings (8) within the Moss Landing Harbor, 3,896 acres of farm land, and 85,798 feet of road located within this 100-year flood zone. Most residential development is located outside of the FEMA flood zone.

Recent flooding events resembled that projected by the FEMA Flood Hazard maps. On December 11, 2014, localized rainfall within the Gabilan hills caused discharges of almost 700cfs within the Reclamation Ditch (Gabilan Creek) while, during that same period, the Salinas River flow did not surpass 10cfs (Figure 7). River flows increased during winter king tides, reducing discharge capacity through the Potrero and Moss Landing tide gates, causing significant flooding of agriculture lands within the lower Salinas Valley. Flood damage was estimated at more than two million in crop losses.

[18] This study did not investigate the risks from increased heat, decreases in water supply or increases in threats from fire that are also predicted due to climate change.

Flooding as projected within the FEMA 100-year hazard maps is expected to become more frequent (i.e. 10–20 year intervals) due to changing rainfall patterns associated with climate change. The Monterey County Hazard Mitigation Plan suggests that, "Based on previous occurrences, Monterey County can generally expect a serious flood event to occur every 4 years." The future threats from increases in river flows during less frequent but more intense rain events were investigated within this project and are reported in Section 5.3.

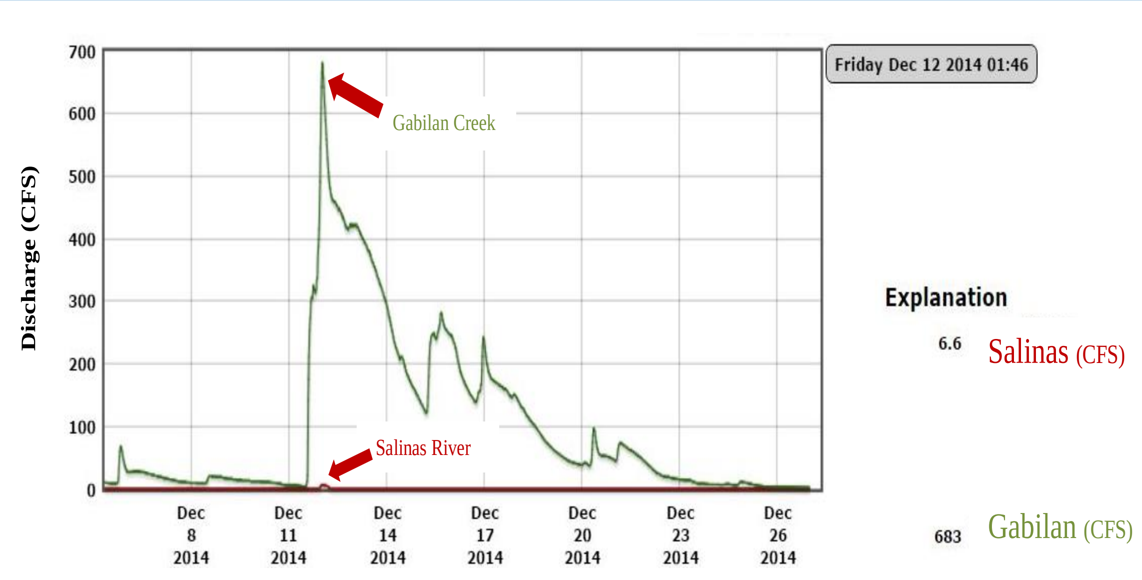


Figure 7. Discharge Rate at Gabilan Creek and Salinas River in December 2014
(Figure source: ESA 2016)

ESA Existing Hazards (2010)

The combined risks from current climatic conditions (2010 model years[19]) were evaluated for the Moss Landing Community and are listed in Table 5. The Existing hazard zone is shown in Figure 8. Much of the vast wetland and creek habitat within the Moss Landing area can flood during high tides except where those resources are managed behind tide gates. Most properties below high tide elevation within the Elkhorn, Bennett and the lower Moro Cojo Slough (except along the Moss Landing Road commercial district) have been purchased for habitat restoration or conservation (one last parcel within the Moro Cojo is currently targeted for acquisition). Low lying areas adjacent to the Old Salinas River, Tembladero Slough/Gabilan drainage and Castroville Slough are located behind tide gates that limit tidal range within these drainages or are behind pump stations that actively pump water from low lying areas. These management strategies allow these areas to be productive farm land (some of these parcels are only farmed during dry summer months) even though many are below sea level.

The 2010 ESA Sea Level Rise risk models correlate well with the FEMA flood maps (FEMA flooding extends further inland) within the Elkhorn and Moro Cojo Slough areas but differ greatly within the OSR

[19] The fluvial analysis used 2015 existing condition year.

and Tembladero areas (Figure 8). The discrepancies within the lower Salinas Valley are likely do to small differences in DEM elevation base layers and drainage network maps within this flat low-lying valley. A combination of the two hazard maps most likely best reflects current flooding vulnerabilities within this area. The 1995, 1998, 2014 and 2017 flood events can be used to corroborate the flood risk vulnerabilities within this drainage[20].

The 2010 ESA Sea Level Rise risk models (excluding wave derived coastal flooding behind tide gates) project that 15 residential and 23 commercial properties and 12,483 feet of road (including parts of Hwy 1 south and north of the Elkhorn Slough Bridge) are presently vulnerable to the impacts of Coastal Climate Change (Table 5). Most of this same infrastructure was impacted during the 1998 flood.

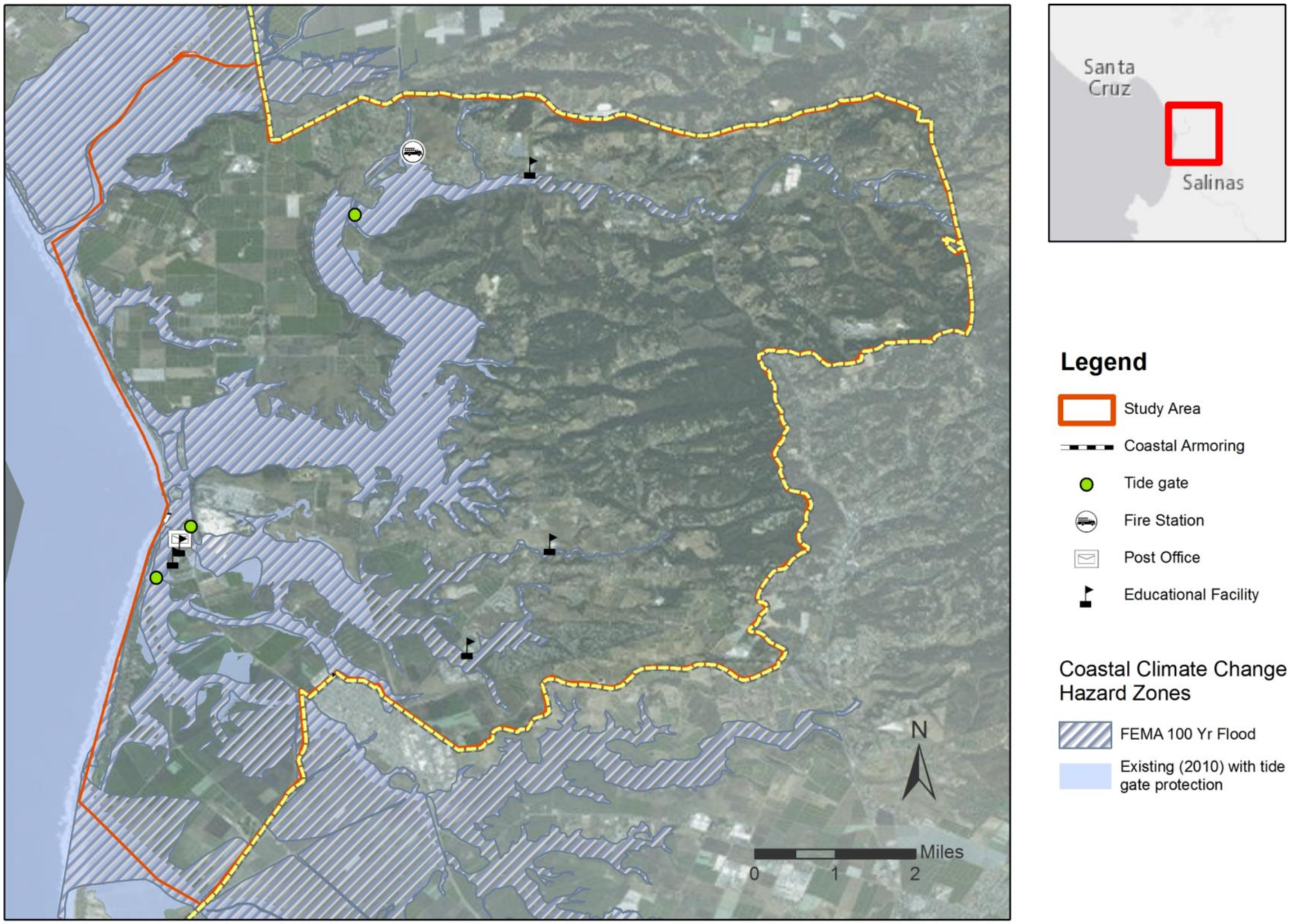
Additional residents and businesses within the 2010 hazard zone are located within the Castroville community further inland from the Coastal Zone along the Gabilan/Reclamation Ditch drainage (outside the study area of this report).

[20] Watershed Education Outreach Program. 1995. *Salinas Valley Flood Report*

Table 5. Comparison of FEMA and ESA Existing (2010) Hazard Zones

ASSET	UNITS	TOTAL	FEMA	2010 (WITH ARMOR)
Land Use and Buildings				
Total Buildings	Count	6,642	327	88
Residential	Count	5,815	219	15
Commercial	Count	71	13	23
Public	Count	52	14	3
Visitor Serving	Count	3	0	2
Other	Count	701	81	45
Educational Facilities	Count	5	0	0
Post Offices	Count	1	0	1
Emergency Services	Count	1	0	0
Farmland	Acres	15,393	3,896	1,951
Transportation				
Roads	Feet	687,784	62,175	12,483
Rail	Feet	45,730	24,438	7,123
Highway 1	Feet	62,949	15,050	3,324
Parks, Recreation, and Public Access				
Parks	Acres	6,513	2,274	2,536
Beaches	Acres	161	80	143
Coastal Access Points	Count	17	5	3
Parking Lots	Acres	9	3	1.5
Water and Utility Infrastructure				
Storm Drains	Feet	29,201	4,336	0
Culverts and Tide Gates	Count	29	23	21
Natural Resources				
Dunes	Acres	1,227	565	607
Critical Habitat	Acres	2,306	925	389
National Wetlands	Acres	5,889	4,669	1,526

Figure 8. Existing (2010) Flood Modeled Hazard Zone Compared to FEMA 100-Year Flood zone



4.3 Summary of Future Vulnerabilities by Planning Horizon

Due to climate change, the cumulative number of Moss Landing properties and infrastructure at risk will increase between 2010 and 2100 as projected ocean water elevation and storm intensity increase. Impacts during early time horizons (2030) will most commonly result from infrequent storm induced flooding and erosion. Hazards associated with fluvial and tidal flooding will increase during future time horizons (2060 and 2100). The assets at risk from the combined effects of "coastal climate change" are presented in tables below for each time horizon (Table 6).

Secondly, the technical team determined that it is likely that all coastal protection infrastructure (sea walls, rip-rap, and groins) will need to be replaced or significantly improved at some point before 2060, and therefore the 2060 and 2100 coastal erosion analyses do not account for the protections provided by existing structures. Rather, the analysis accounts for the expected lifespan of coastal structures and assumes that future actions must be taken to replace structures if the community intends to mitigate these projected hazards. This approach to future hazard analysis recognizes that current coastal armoring may continue to provide protection from wave impacts through 2030 but may fail prior to 2060. The map at the end of this section documents the combined coastal climate change hazard zones for 2030, 2060, and 2100 which includes dune erosion, frequent to annual wave damage and storm related flooding, and areas where increases in sea level will lead to monthly inundation during high tides Figure 9).

2030

For 2030, the vulnerability analysis assumed that current coastal protective structures will still be present and functioning. The most critical protective structures within the Moss Landing area are the two tide gates that control tidal range flooding within the lower Salinas Valley along the Old Salinas River and Tembladero Slough (Potrero Road tide gates) and Moro Cojo Slough (Moss Landing Road tide gates). The 2030 analysis accounts for the reduction of inland flooding that these structures provide. River flooding, however, remains a hazard.

Buildings and Land Use: The list of properties at risk from the combined effects of coastal climate change for 2030 (excluding flooding behind tide structures) is similar to those projected at risk within the 2010 initial condition evaluation. FEMA flood maps extend the hazard zone within the lower Salinas Valley past that projected by the ESA 2030 fluvial evaluation. For 2030, a total of 96 buildings are vulnerable to coastal climate impacts (other than areas protected from coastal flooding behind tide gates), only 8 more than currently at risk (2010 vulnerability assessment). Ten of these buildings are located on Moss Landing Island, approximately 20 are located in the commercial district, and 10 in the Potrero Road Residential Neighborhood.

Transportation: 20,279 feet of road including parts of Potrero Road, Moss Landing Road, and Hwy 1 (3,894 feet) fall within the combined 2030 hazard zone.

Recreation and Public Access: The beach along the Moss Landing Island is projected to erode inland up to 70ft, placing the current structures within the active wave impact zone. Lateral coastal access in front of these structures will be impacted or eliminated. Erosion of the dunes south of Sandholdt Bridge will reduce the dune width to less than 200ft, decreasing the resiliency of the dunes to mitigate coastal flooding risks to properties inland of the Potrero tide gate.

Natural Resources: Much of the wetland habitat within the Moss Landing/Lower Salinas Valley is within the boundaries of the coastal hazard layers for 2030. However, many of these resources are "protected" from full tidal flooding by the Moss Landing and Potrero road tide gates. A study has begun by researchers at Moss Landing Marine Labs to estimate the adaptive capacity of these wetland resources if tidal ranges increase.

Water Control Structures: Although many of the water control structures (culverts and tide gates) fall within the flood hazard zone, we assume that inundation levels are at a height in which these structures will still function as intended. The fluvial analysis for the Old Salinas River estimates the flow restriction posed by these tide gates based on future projected discharge rates.

2060

By 2060 we assume that coastal armoring and water control structures will no longer function as designed without upgrades or replacement. The 2060 combined hazard zone highlights the areas vulnerable to the combined effects of coastal climate change without these protective structures (tide gates and coastal armoring).

Buildings and Land Use: There is a significant increase in the number of properties at risk of coastal climate change by 2060. The 2060 hazard zone (Figure 9) projects almost complete loss of services on the island during storms by the combined effects of coastal climate change unless protective structures are upgraded or beach nourishment and sand dune enhancement efforts are increased significantly. Almost all the buildings within the commercial district and approximately half the homes within the Monterey Dunes Colony fall within the 2060 combined hazard zone.

Transportation: Erosion and wave overtopping risks are projected to impact the north harbor along Jetty Road. Storm surge and larger river discharges into the Moss Landing Harbor are projected to cause flooding of the Moss Landing Road area. The flood protection provided by the Moss Landing Road tide gates for the Moro Cojo watershed is assumed to be compromised. Much of the Hwy 1 corridor within the planning area is projected to be vulnerable to flooding.

Water Control Structures: By 2060 many of the existing tide gates and culverts will not have the capacity to address the combined impacts of coastal storm flooding and rising tides.

Natural Resources: Coastal erosion compromises sand dune's ability to restrict wave overtopping and flooding within the lower Salinas Valley. By 2060 erosion of the dunes near Potrero road and near the Salinas River mouth are at risk of storm wave overtopping, leading to waves flowing into the Old Salinas River channel, bypassing the coastal flood protections provided by the tide gates and river levees. This inland migration of beach along this portion of the coast poses a significant risk to the Salinas Valley if the dunes are not encouraged to migrate inland with the coastline. Such migration will of course lead to serious conflicts with adjacent agriculture and the current alignment of the Old Salinas River.

2100

By 2100 the increased height of monthly tides becomes the driving hazard for Moss Landing adaptation planning.

Buildings and Land Use*:* Monthly high water is projected to flood much of the Moss Landing Road commercial district and portions of the Moss Landing Island/Sandholdt Road mixed use district. Winter wave overtopping and dune erosion will become significant hazards for land uses within the harbor as the sand spits along Sandholdt and Jetty road are reduced in width by erosion. By 2100, 272 buildings are located within the projected hazard zone.

By 2100, wave run-up energy will be greater during most storms causing flood and wave damage within the harbor. River flooding is projected to be significant and more frequent. Much of the agriculture lands south of Moss Landing and west of Highway One will be vulnerable to flooding due to further dune erosion and loss of water control structure functions.

Water Control Structures: In 2100, many of the passive water control structures located throughout the Moss Landing area will fail to work as designed leading to inland flooding.

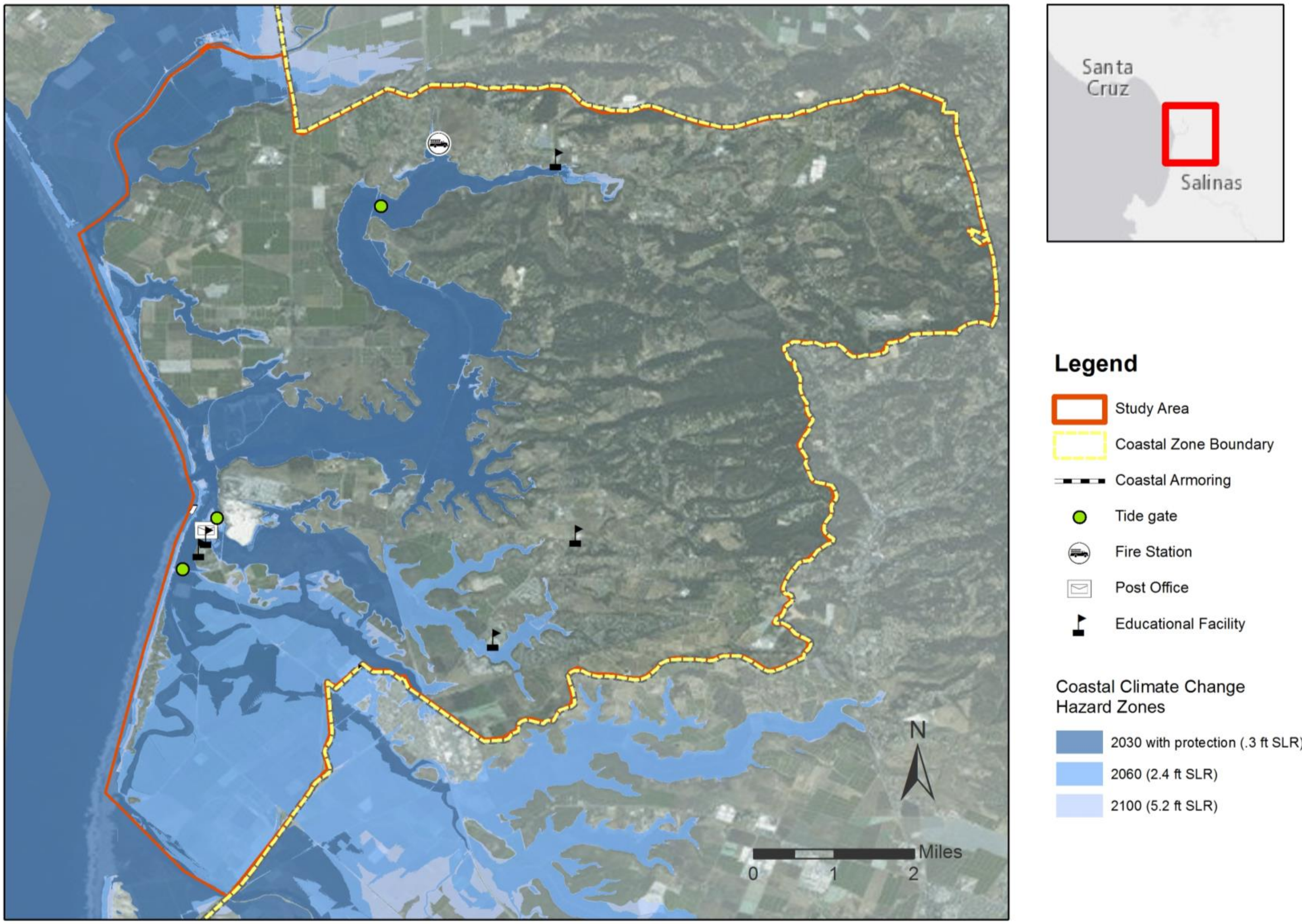
Transportation*:* By 2100, 73,286 feet of road (including Hwy 1) fall within the combined hazard zone. Much of the transportation infrastructure will need to be raised, moved, or allowed to flood as tidal height increases and the functionality of current water control structures is reduced.

Natural Resources: The Old Salinas River channel and Harbor main channel are vulnerable to coastal wave processes as the dunes along this stretch of coast experience the effects of “coastal squeeze.” Within these areas the dune faces are projected to erode inland while the location of inland development remains static. Three sections of the coastal sand spit are vulnerable to loss from coastal erosion. The failure of these dunes will likely lead to significant changes in how (or if) the harbor and Sandholdt sand spit development continues to function. Additionally, many of the surrounding freshwater wetlands resources may be negatively impacted by the increased tidal range.

Table 6. Vulnerability of Assets due to Combined Effects of Coastal Climate Change

ASSET	UNITS	TOTAL	2030 (WITH ARMOR)	2030 (NOARMOR)	2060 (NO ARMOR)	2100 (NO ARMOR)
Land Use and Buildings						
Total Buildings	Count	6,642	96	139	198	272
Residential	Count	5,815	17	21	59	113
Commercial	Count	71	25	25	28	32
Public	Count	52	3	3	6	8
Visitor Serving	Count	3	3	3	3	3
Other	Count	701	48	87	102	116
Schools	Count	5	0	1	1	1
Post Offices	Count	1	1	1	1	1
Emergency Services	Count	1	0	0	0	0
Farmland	Acres	15,393	1,991	4,731	5,290	5,532
Transportation						
Roads	Feet	687,784	20,279	50,746	73,286	95,284
Rail	Feet	45,730	7,855	11,280	15,901	24,728
Highway 1	Feet	62,949	3,894	14,464	22,780	29,040
Parks, Recreation, and Public Access						
Parks	Acres	6,513	2,547	2,584	2,746	2,834
Beaches	Acres	161	143	143	160	161
Coastal Access Points	Count	17	5	5	11	13
Parking Lots	Acres	9	2	2	5	9
Water and Utility Infrastructure						
Storm Drains	Feet	29,201	0	80	100	172
Culverts and Tide Gates	Count	29	19	20	22	24
Natural Resources						
Dunes	Acres	1,227	636	736	894	969
Critical Habitat	Acres	2,306	1,048	1,126	1,361	1,629
National Wetlands	Acres	5,889	3,382	4,074	4,387	4,495

Figure 9. Hazard Zones for the combined effects of future coastal climate change
(Excludes flooding behind existing tide gates from rising tides and coastal storms for planning horizon 2030)



5. Vulnerability by Coastal Hazard

The hazards associated with each of the modeled coastal processes (coastal storm flooding, coastal erosion, rising tides and fluvial flooding) threaten various types of coastal infrastructure differently. Wave and fluvial flooding can damage buildings, and temporarily restrict use of public amenities, make storm drains and tide gates ineffective and limit the use of roads and walkways. Many of these impacts are temporary and repairs can be made. Dune erosion and monthly high tide flooding, however, are permanent impacts that will lead to extensive rebuilding, a change in use or abandonment of the property. By analyzing the impacts due to separate coastal hazards, coastal resource managers can begin to plan adaptation strategies accordingly (see Section 7 for a discussion on adaptation strategies).

5.1 Rising Tides

Though the projected hazard extent for rising tides is less than for coastal storm and river flooding, the impact is more frequent. Tidal range is projected to increase by 0.3 feet by 2030, 2.4 feet by 2060 and 5.2 feet by 2100 (Table 7). The projected extent of the rising tides hazard zones within the study area are shown in Figure 10. Buildings projected to be impacted within the Moss Landing Community Plan Area are shown in Figure 11.

Table 7. Extreme Tide Conditions for Reclamation Ditch System

TIME PERIOD	SEA LEVEL RISE (FT)		10- YEAR TIDE LEVEL + SLR (FT NAVD)	
	Medium	**High**	**Medium SLR**	**High SLR**
2030	0.3	0.7	8.0	8.4
2060	1.1	2.4	8.8	11.0
2100	2.9	5.2	10.6	12.9

By 2030, the tidal estuary habitat of the Old Salinas River, Bennet Slough and Elkhorn Slough will be flooded during normal high tides. Unless rapid marsh plain accretion occurs, this tidal flooding will risk further marsh plain die back and a transition to mud flat. An increase in tidal flooding occurred in 2014 after the failure of the Moro Cojo tide gates which allowed the estuary to fill slowly over numerous months with saltwater (tidal range did not appear to increase). Portions of the Moro Cojo Slough were inundated with salt water above the habitats normal range, leading to the dieback of fringing brackish and freshwater plant communities.

No buildings are within the projected 2030 tidal flood extent. However, by 2060, 18 structures within the commercial district are vulnerable to high tides if the Moss Landing Road tide gates do not continue to regulate tidal exchange within the Moro Cojo Slough. By 2060 most parking areas around the harbor are vulnerable to monthly flooding and most of the properties along Moss Landing Road are projected to be flooded every month. Portions of Moss Landing and Jetty roads will be flooded by 2060 as well as a number of buildings on the Moss Landing Island adjacent to the harbor. Coastal Access along the harbor and Potrero Road will also be flooded more frequently (Table 8).

By 2100 most of the development within the Moss Landing Commercial and harbor areas will be flooded monthly during high tides. Only limited flooding risk is projected for the residential area along Potrero Road. A total of 1,170 feet of roads are vulnerable to monthly high tides at 2030 within the Moss Landing Community; rising to 12,278 by 2060 and 30,834 ft. by 2100. Tides will flood more than 11,000 feet of Highway 1 within the Moss Landing Study Area by 2100.

Some farmland in the lower Salinas Valley is already vulnerable to flooding during high tides. However, this risk is reduced significantly by the Potrero and Moro Cojo tide gates. The proper function of these tide gates is dependent on water elevations within the harbor. As ocean levels rise, these gates will be less able to maintain current inland water levels and flooding is expected to increase within Salinas Valley agriculture fields. By 2100, 3,168 acres of farmland within the Moss Landin Study Area are projected to flood monthly.

Table 8. Assets Vulnerable to Rising Tides

ASSET	UNITS	TOTAL	2030 (WITH PROTECTION)	2060 (NO PROTECTION)	2100 (NO PROTECTION)
Land Use and Buildings					
Total Buildings	Count	6,642	7	58	106
Residential	Count	5,815	2	8	19
Commercial	Count	71	2	25	31
Public	Count	52	0	3	8
Visitor Serving	Count	3	0	3	3
Other	Count	701	3	19	45
Education Facilities	Count	5	0	1	1
Post Offices	Count	1	0	1	1
Emergency Services	Count	1	0	0	0
Farmland	Acres	15,392	92	1,572	3,168
Transportation					
Roads	Feet	687,784	1,170	12,278	30,834
Rail	Feet	45,730	3,313	12,636	21,072
Highway 1	Feet	62,949	1,095	4,850	11,691
Parks, Recreation, and Public Access					
Parks	Acres	6,513	1,946	2,480	2,552
Beaches	Acres	161	15	43	63
Coastal Access Points	Count	17	1	3	8
Parking Lots	Acres	9	0	2	8
Water and Utility Infrastructure					
Storm Drains	Feet	29,201	0	56	139
Culverts and Tide Gates	Count	29	9	22	24
Natural Resources					
Dunes	Acres	1,227	200	574	688
Critical Habitat	Acres	2,306	803	975	1,254
National Wetlands	Acres	5,889	2,524	3,961	4,322

Figure 10. Rising Tides (Extreme Monthly High Water) Hazard Zones within Study Area

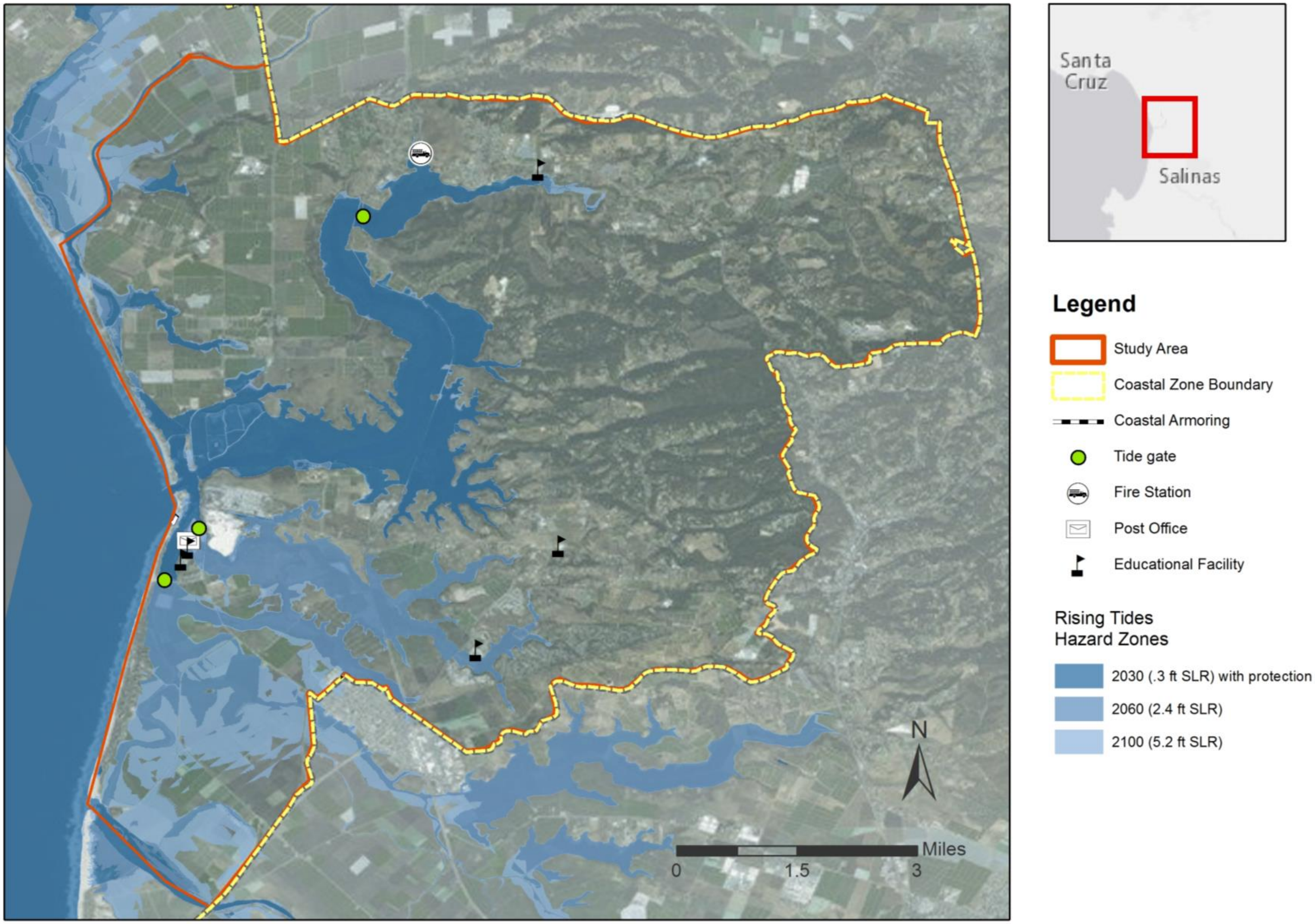
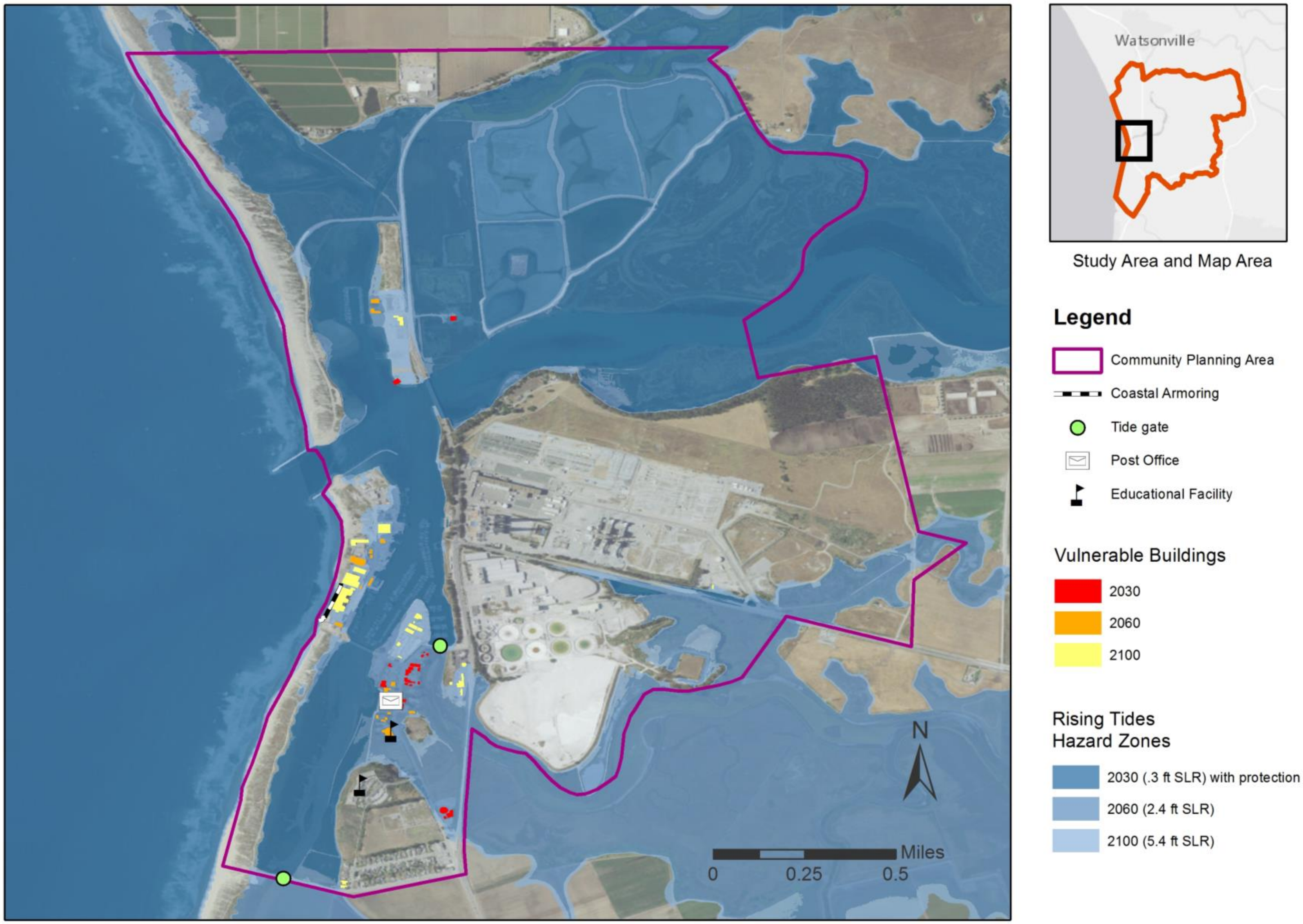


Figure 11. Buildings within the Moss Landing Community Plan Area vulnerable to Rising Tides (Extreme Monthly High Water)



5.2 Coastal Storm Flooding and Wave Impacts

Due to climate change, the cumulative number of Moss Landing properties and infrastructure at risk increases as projected ocean water elevation and storm intensity increase (i.e. Coastal Storm Flooding). Coastal Flooding risks arise during winter storms with increased local sea level (exacerbated by off shore high pressure systems) and increases in wave height and energy (due to storm related winds) leading to wave impacts and localized flooding from water overtopping dunes and other coastal structures. The ESA risk models estimated both wave run-up extent and height of water for the Moss Landing coastline and harbor areas. The projected coastal storm flood hazard zones, within the study area for time horizons 2030, 2060, and 2100, are shown in Figure 12.

For 2030, the coastal flooding vulnerability analysis assumes that current tide gate and coastal protective structures will remain functioning. Regardless, coastal flooding will be a significant threat for Moss Landing by 2030. Coastal dunes that protect inland wetland habitat, agriculture, urban development and the Moss Landing Harbor all will be impacted by the increased force of wave energy, leading to the loss of dune habitat and the possible overtopping of the dunes near the Salinas River mouth, risking inland flooding. Brackish water resources and agriculture lands further inland are vulnerable to saltwater inundation if the dunes and/or tide gates fail to restrict connectivity between coast and creek.

Structures on Moss Landing Island adjacent to the shore will see more frequent and severe wave damage due to coastline migration (water line migration and wave run-up encroachment inland while infrastructure locations remain static). Figure 13 identifies properties in the Moss Landing Community Plan Area that will be impacted by coastal storm flooding. Due to the Moss Landing Harbor deep water channel, storm surge and flooding can migrate up the channel into the heart of the Moss Landing community, increasing flood hazards to much of the community. The assets vulnerable to coastal storm flooding in each planning horizon for the entire study area are presented in Table 9.

This study assumes that tide gates that protect southern Moss Landing, Castroville and the Salinas Valley from flooding during current high tide events will fail to provide flood protection from the projected hazards of 2060 ocean derived storms. Rather, this analysis assumes that future actions must be taken to mitigate these projected hazards. Therefore, this analysis identifies the infrastructure vulnerable to future coastal flooding if these structures are not replaced or upgraded.

By 2060, coastal flooding is projected to circumvent the Moro Cojo tidal structure unless new structures are built to restrict storm surge from passing over Moss Landing Road. Cost considerations, feasibility constraints and the secondary implications of tide gate upgrades on coastal resources (water quality, wetland habitat, fish migration) will likely be significant (see Section 6). Depending on construction and operational costs, construction feasibility and legality of replacing current tide gates, land uses behind these structures may need to adapt to the projected flood hazards or be lost.

Projected impacts from coastal flooding (wave overtopping dunes and levees causing inland flooding) demonstrate the dire vulnerabilities that agricultural lands, Moss Landing's coastline, and the surrounding area face in the future. By 2100 several portions of the protective dunes complex are projected to no longer restrict ocean waves, leading to significant flooding within the lower Salinas Valley (69 additional buildings). The long-term preservation of the Salinas State Beach dunes complex and the effective restriction of storm surge inland of Potrero road are critical to the future viability of the southern Moss Landing region. The potential for inward migration of these dunes is likely but will come in conflict with present land use of those properties.

Table 9. Assets Vulnerable to Coastal Storm Flooding and Wave Impacts within Study Area

ASSET	UNITS	TOTAL	2030 (WITH PROTECTION)	2060 (NO PROTECTION)	2100 (NO PROTECTION)
Land Use and Buildings					
Total Buildings	Count	6,642	66	183	259
Residential	Count	5,815	16	44	101
Commercial	Count	71	1	28	32
Public	Count	52	2	6	8
Visitor Serving	Count	3	0	3	3
Other	Count	701	47	102	115
Schools	Count	5	0	1	1
Post Offices	Count	1	0	1	1
Emergency Services	Count	1	0	0	0
Farmland	Acres	15,393	879	5,290	5,532
Transportation					
Roads	Feet	687,784	20,101	72,261	93,486
Rail	Feet	45,730	7,855	15,901	24,729
Highway 1	Feet	62,949	3,903	22,780	29,041
Parks, Recreation, and Public Access					
Parks	Acres	6,513	2,134	2,710	2,808
Beaches	Acres	161	143	149	161
Coastal Access Points	Count	17	4	10	12
Parking Lots	Acres	9	2	5	9
Water and Utility Infrastructure					
Storm Drains	Feet	29,201	0	100	172
Culverts and Tide Gates	Count	29	16	22	24
Natural Resources					
Dunes	Acres	1,227	394	842	945
Critical Habitat	Acres	2,306	1,122	1,346	1,629
National Wetlands	Acres	5,889	2,750	4,387	4,494

Figure 12. Coastal Storm Flood Hazard Zones within Study Area

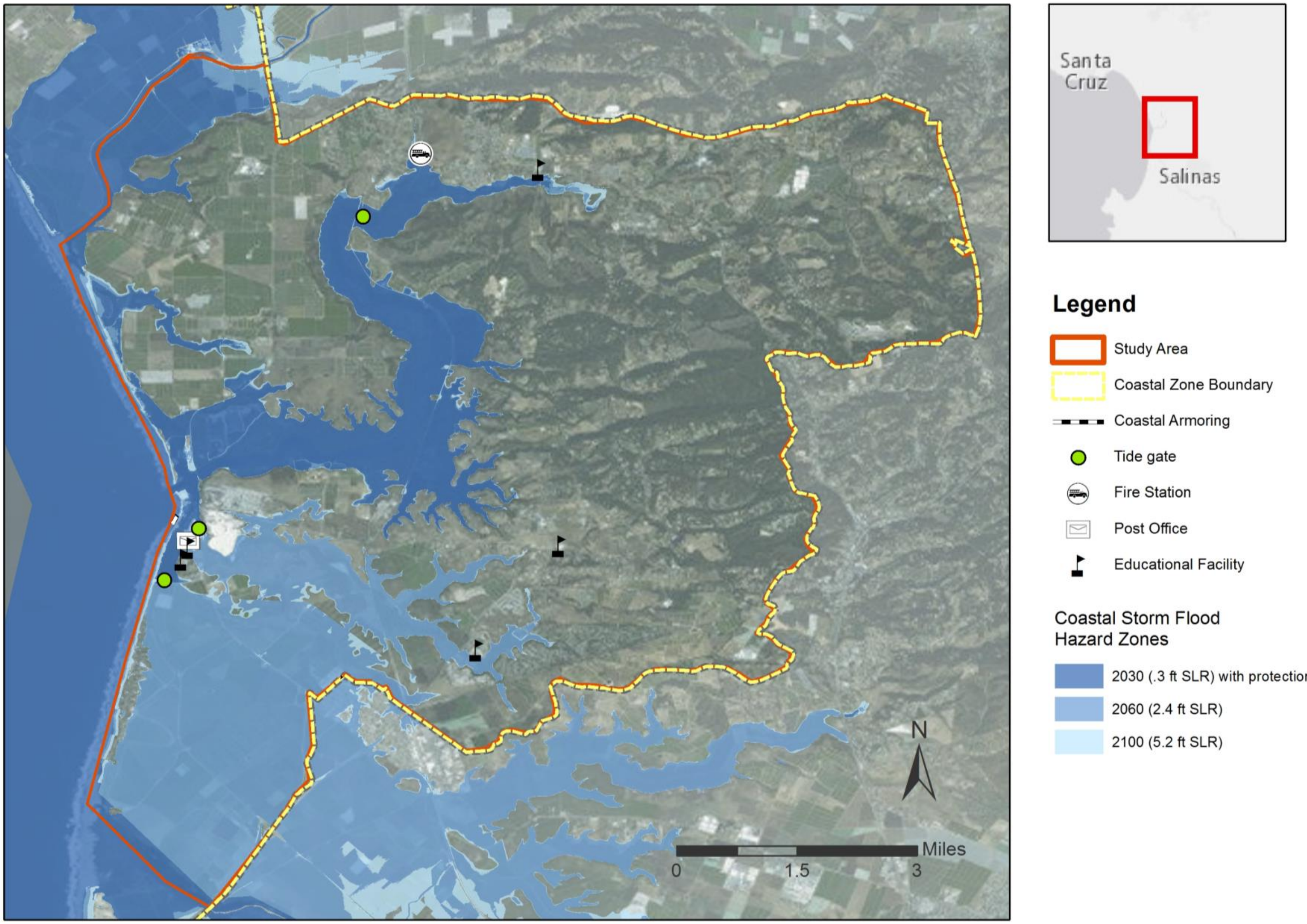
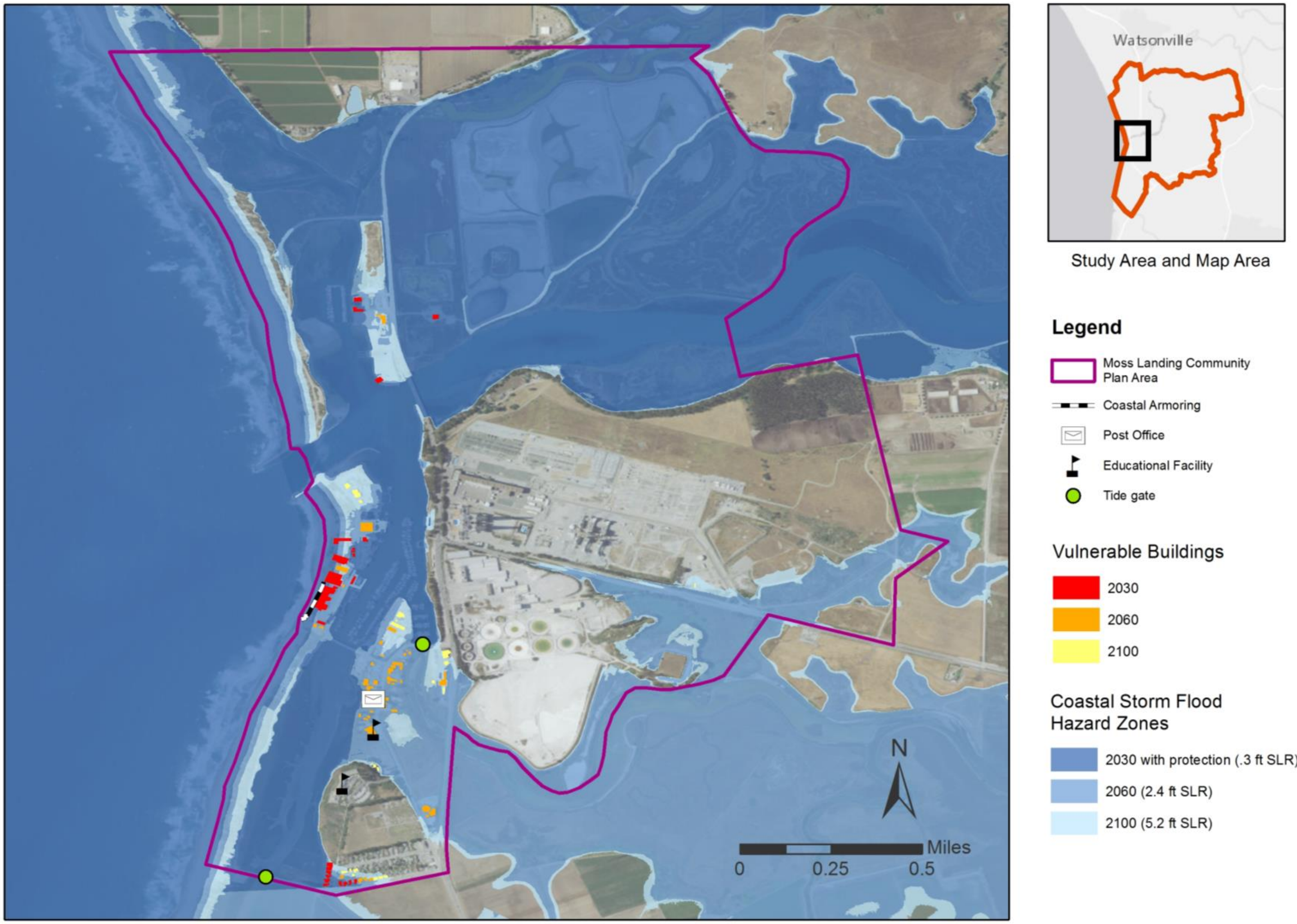


Figure 13. Buildings within the Moss Landing Community Plan Area vulnerable to Coastal Storm flooding



5.3 Fluvial Impacts

The December 11, 2014 storm event in the Salinas hills caused waters to flow down through the Gabilan watershed causing significant flooding within the Moss Landing agriculture fields. Flow within the Gabilan Reclamation Ditch was estimated to be 700 CFS (50-100 times normal flows) while the Salinas River directly south of the Gabilan saw no increase in flow rates (6cfs - demonstrating the local intensity of this rain event). This flooding was exacerbated when the draining capacity of the gates was compromised by high “king” tides causing river floodwaters to back up behind the tide gate structure. The future hazards of river flooding due to the predicted increase in fluvial discharge, higher ocean elevations during storms and higher sea level elevations were evaluated for Moss Landing and the Lower Salinas Valley[21]. The predicted increase in fluvial discharge within the Gabilan/Rec Ditch due to more intense rainfall during storms used for this analysis is outlined in Table 10.

Table 10. Increases in 100-year Discharge for the Reclamation Ditch System Relative to Historic Period (1950-2000)

EMMISIONS SCENARIO	2030	2060	2100
Medium (RCP[22] 4.5 5th percentile)	20% Increase	40% Increase	60% Increase
High (RCP 8.5 90th percentile)	140% Increase	210% Increase	275% Increase

The project team documented flows that occurred during the December 2014 flooding event to test the accuracy of the expanded Gabilan fluvial model. The model accurately projected the back watering within the Old Salinas River and the rerouting of the floodwaters under the Highway 1 into the Moro Cojo Slough (Figure 14). Future revisions to this fluvial model will be made as part of the 2017 Greater Monterey IRWMP storm water planning effort to provide additional information on the potential flood reduction potential if the Old Salinas River, the Salinas River lagoon and the Moro Cojo estuaries were strategically managed.

[21] ESA. 2016. *Climate Change Impacts to Combined Fluvial and Coastal Hazards*. May 13, 2016.

[22] The World Climate Research Programme under the Coupled Model Intercomparison Project Phase 5 uses emissions scenarios referred to as Representative Concentration Pathways (RCPs). The highest scenario, RCP 8.5, reflects a track with little mitigative measures to reduce greenhouse gas emissions resulting in a net increase in radiative forcing of 8.5 W/m2 by 2100 relative to pre-industrial conditions. A medium level emissions scenario, RCP 4.5, reflects a future wherein changes in technology and energy usage stabilize the increase in net radiative forcing to 4.5 W/m2 by 2100. These emissions scenarios, RCP 4.5 and RCP 8.5, were used to reflect respectively medium and high emissions trajectories for this study

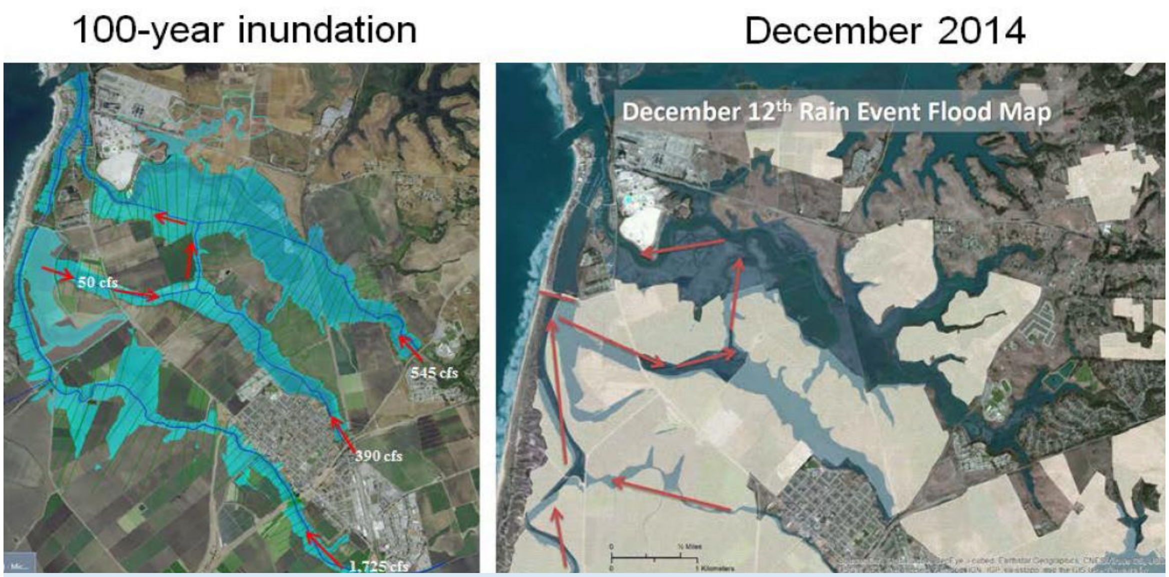


Figure 14. Comparison of Modeled 100-year flow paths and observed flow paths during Dec 2014 flood (Figure source: ESA 2014)

Currently, residential and business properties in Moss Landing have been build adjacent to, but above the FEMA flood plain. A significant area of the lower Salinas Valley agriculture fields, however, is currently vulnerable to flooding from the Gabilan Watershed and Old Salinas River (Image 1). Many of the farm fields vulnerable to flooding within the Moro Cojo Slough have been purchased for wetland restoration or conservation. Other historical wetland areas within the Gabilan drainage between Castroville and Salinas remain in agriculture production through the aid of water lift stations that pump water from drainage systems in the low-lying areas. Water elevation within these basins can be more than 8ft below sea level. Obviously, these areas are vulnerable to flooding in the winter and have (inadvertently) provided flood attenuation service to downstream resources during flood events.

Image 1. February 20th, 2017 flooding of lower Salinas Valley (note similarities with hazard map Fig. 14) (Photo: KSBW drone footage)

Flooding risks projected within the ESA climate change models identify only small additional areas of agriculture land vulnerable to fluvial flooding by 2030. The area of flooding however increases significantly within the lower Salinas Valley (west of Hwy 1) by 2060 and 2100 as the combined effects of SLR and changing rainfall patterns increase significantly (Figure 15).

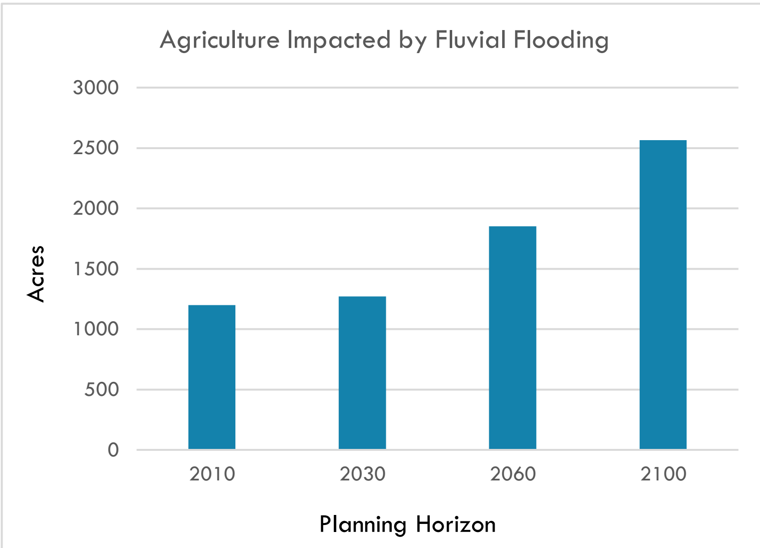


Figure 15. Agriculture Impacted by Fluvial Flooding

As many as 1,852 acres of agriculture land behind the two tide gates will be routinely flooded by 2060 unless tide gates are replaced with new structures that can accommodate higher flows (>700cfs) and higher tides (2.4 ft.) (Table 11). Salinas Valley agricultural fields are vulnerable to increased frequency and elevation of flooding as well as the potential for salt water inundation that may reduce the productivity of these fields. Periodic flooding of agriculture fields also risks significant food safety liabilities for the industry.

Storm intensity is predicted to increase within Monterey County by 2100. These more infrequent but intense rainfall events are predicted to cause rivers and creeks to rise rapidly leading to downstream flooding within the vast low-lying Salinas Valley. The projected fluvial flood hazard zones for the 2030, 2060 and 2100 time horizons are depicted in Figure 16. Buildings within the Moss Landing Community Plan area that are projected to be impacted by flooding from the Reclamation Ditch are shown in Figure 17.

Areas adjacent to the Tembladero and Castroville slough channels, directly outside of our study area, are vulnerable to storm and climate induced flooding. In the community of Castroville, the 2030 hazards projected are similar to the FEMA Flood Zone maps. Additional flooding impacts are projected for the northern portion of Castroville due to the added effects of coastal storm induced flooding. The projected coastal flood hazard zone is similar to the flooding extent experienced during the 1995 flood. By 2060, a slightly greater portion of the community of Castroville (areas adjacent to the Tembladero and Castroville slough channels) is vulnerable to storm and climate induced flooding. A significantly greater area of agriculture land will be flooded as discharges within the OSR and Tembladero/Gabilan drainages are impeded by higher water elevations within the harbor due to sea level rise. Increased ocean elevations during winter storms will further increase flooding during winter storm events.

Table 11. Assets Vulnerable to Fluvial Flooding

ASSET	UNIT	TOTAL	2030 (WITH PROTECTION)	2060 (NO PROTECTION)	2100 (NO PROTECTION)
Land Use and Buildings					
Total Buildings	Count	6,642	36	46	84
Residential	Count	5,815	1	2	8
Commercial	Count	71	24	24	29
Public	Count	52	1	2	6
Visitor Serving	Count	3	3	3	3
Other	Count	701	7	15	38
Educational Facilities	Count	5	0	1	1
Post Offices	Count	1	1	1	1
Emergency Services	Count	1	0	0	0
Farmland	Acres	15,393	1,272	1,852	2,565
Transportation					
Roads	Feet	687,784	3,113	11,118	17,712
Rail	Feet	45,730	0	0	0
Highway 1	Feet	62,949	562	3,964	6,551
Parks, Recreation, and Public Access					
Parks	Acres	6,513	433	444	450
Beaches	Acres	161	0	0	0
Coastal Access Points	Count	17	1	2	6
Parking Lots	Acres	9	0	2	3
Water and Utility Infrastructure					
Storm Drains	Feet	29,201	0	0	7
Culverts and Tide Gates	Count	29	5	6	6
Natural Resources					
Dunes	Acres	1,227	323	422	489
Critical Habitat	Acres	2,306	0	1	2
National Wetlands	Acres	5,889	910	985	1,072

Figure 16. Reclamation Ditch Fluvial Flood Hazard Zones within the Study Area.

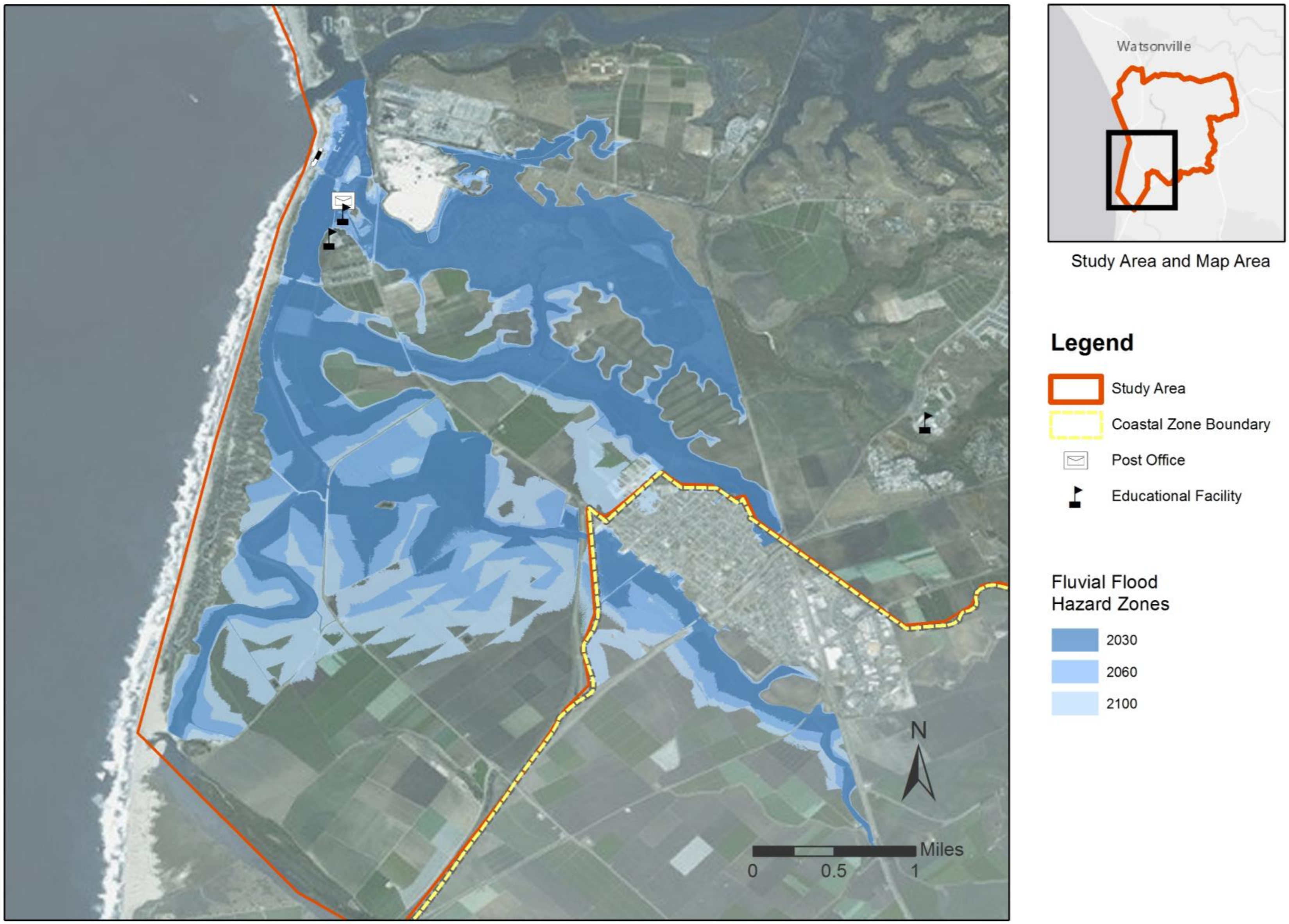
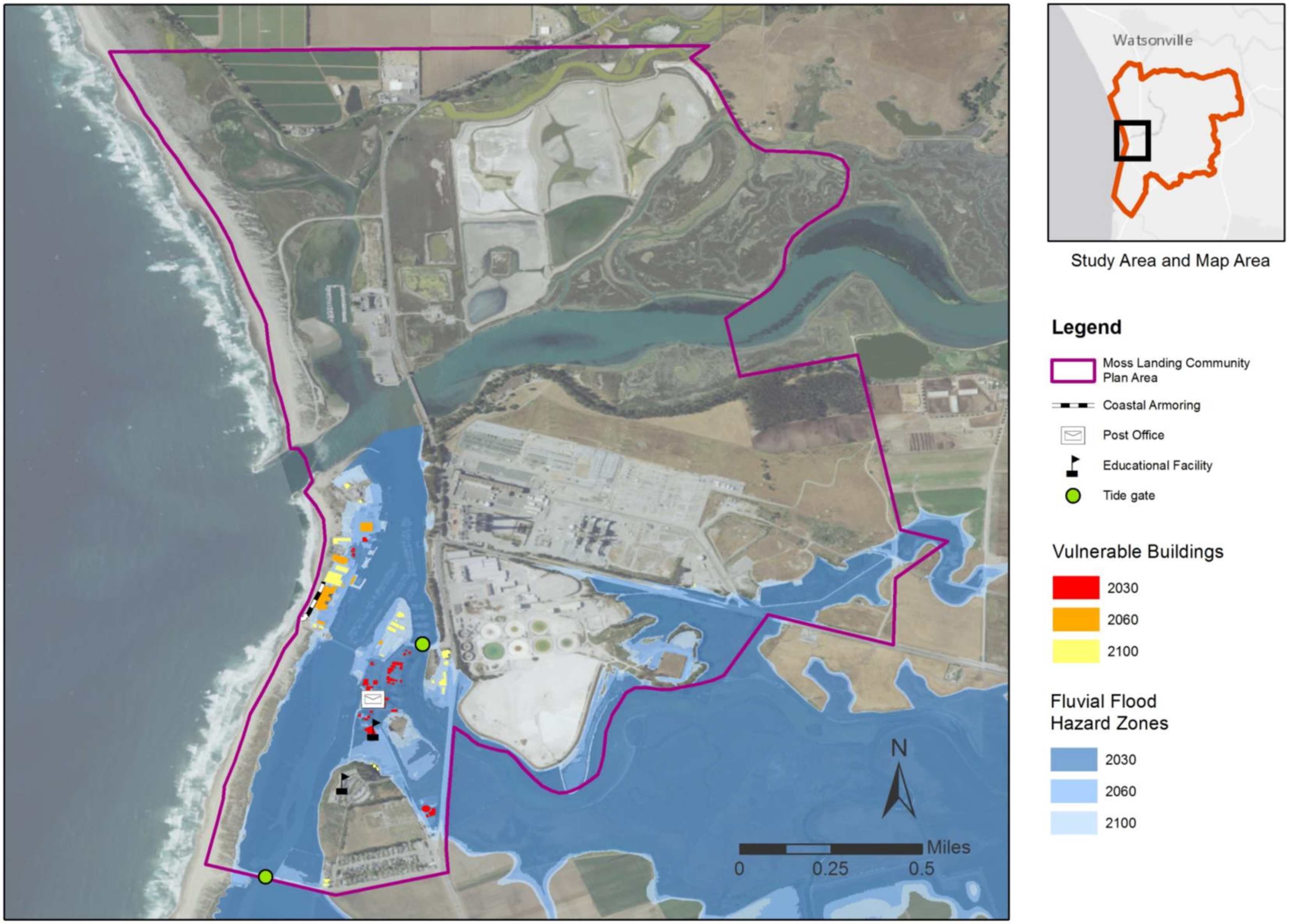


Figure 17. Buildings within the Moss Landing Community Plan Area vulnerable to Fluvial Flooding from the Reclamation Ditch



5.4 Coastal Dune Erosion

Currently several properties are threatened by wave impacts and are protected by a variety of armoring and dune enhancement projects. By 2030, erosion within the dune face of Moss Landing Island is projected to affect two permanent buildings, several portable facilities and 150 acres of park land (Table 12).

Coastal dune erosion and wave overtopping threaten the Salinas River and Moss Landing State Beaches, jeopardize the functionality of visitor serving amenities and reduce the buffering capacity of the dunes to protect inland natural, urban and agricultural resources.

Significant portions of these beach dunes are projected to be vulnerable to coastal erosion by 2060, causing the loss of 278 acres of dune habitat and risking bisection of the linear dune system in at least three locations (Figure 18). This hazard threatens dune habitat and reduces the protective buffer the dunes play for inland resources.

Figure 18. Dunes along the Moss Landing Coast vulnerable to Coastal Erosion

Sand dunes south of Sandholdt Road are projected to be breached by coastal erosion before 2060 leading to the creation of an alternate discharge/inlet to the ocean that will compromise current harbor functions further. By 2060, large portions of the dunes between the Salinas River and Sandholdt Road are projected to be bisected by wave induced erosion, leading to wave overtopping and flooding of the Old Salinas River and Salinas Valley. Buildings vulnerable to projected erosion hazards both within the Moss Landing Community Plan Area and the Monterey Dunes Colony are shown in Figure 19. Portions of the Monterey Dunes Colony are vulnerable to impacts from dune erosion by 2060 and most properties (88%) are vulnerable by 2100.

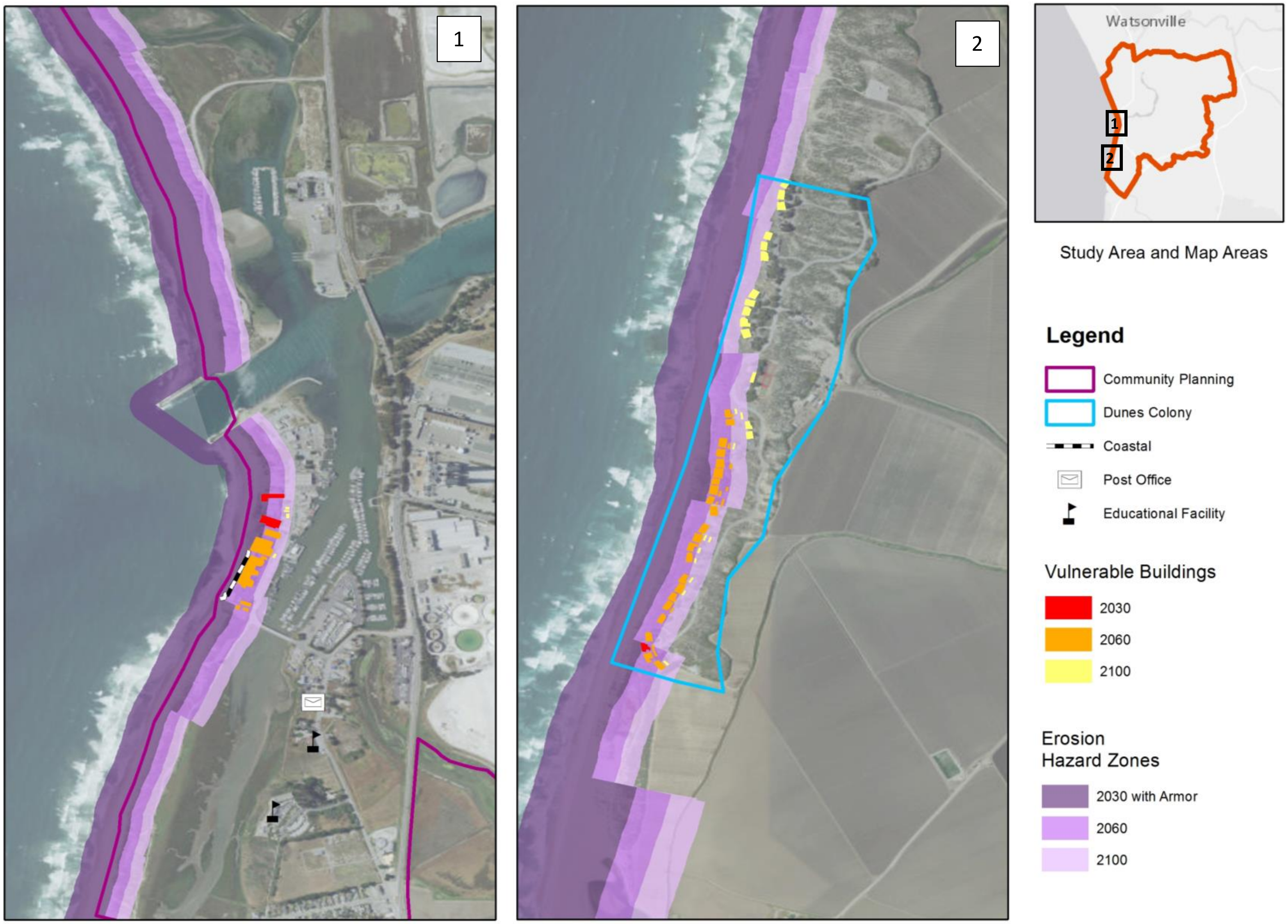
Some coastal access points (along Jetty and Sandholdt roads) may be compromised by coastal dune erosion and wave overtopping. Several older coastal protection structures (rip-rap and concrete rubble) are present along the Moss Landing Island but were not included in the CCC GIS layer. Additional information on these hip walls, rip-rap and dune stabilization efforts is needed to improve the dune erosion projections along Moss Landing Island.

Unless current coastal armoring is upgraded, new structures are constructed along the island, or natural adaptation strategies are put in place, erosion is projected to progress inland to the edge of Sandholdt road by 2060, threatening 8 structures (Figure 19). By 2100, ESA erosion models project ocean waves will bisect the dunes of Moss Landing Island in numerous locations. This erosion threatens 11 structures along Sandholdt Road between the parking lot south of Sandholdt Bridge and Phil's Fish Market. Harbor side infrastructure north of the Moss Landing Marine Labs Small Boats Operations are inland of the modeled erosion zone but within the projected winter flood area.

Table 12. Assets Vulnerable to Coastal Erosion

ASSET	UNITS	TOTAL	2030 (WITH PROTECTION)	2060 (NO PROTECTION)	2100 (NO PROTECTION)
Land Use and Buildings					
Total Buildings	Count	6,642	3	41	71
Residential	Count	5,815	1	32	56
Commercial	Count	71	0	0	0
Public	Count	52	0	0	0
Visitor Serving	Count	3	0	0	0
Other	Count	701	2	9	15
Educational Facilities	Count	5	0	0	0
Libraries	Count	0	0	0	0
Post Offices	Count	1	0	0	0
Cultural Resources	Count	0	0	0	0
Farmland	Acres	15,392	0	3	19
Transportation					
Roads	Feet	687,784	0	1,744	5,992
Rail	Feet	45,730	0	0	0
Highway 1	Feet	62,949	0	0	0
Parks, Recreation, and Public Access					
Parks	Acres	6,513	150	277	347
Beaches	Acres	161	118	153	160
Coastal Access Points	Count	17	1	7	7
Parking Lots	Acres	9	0	1	0
Water and Utility Infrastructure					
Storm Drains	Feet	29,201	0	0	0
Culverts and Tide Gates	Count	29	0	0	0
Natural Resources					
Dunes	Acres	1,227	131	278	425
Critical Habitat	Acres	2,306	0	235	305

Figure 19. Buildings projected to be vulnerable to erosion within the Moss Landing Community Plan Area and Monterey Dunes Colony



5.5 Future Risks of Specific Infrastructure

This hazard analysis highlights the need for long-range coastal management planning that sets policies regarding how best to balance local interest to protect public and private properties with costs associated with construction and impacts to the beach and coastline that result from these protective structures. A list of specific assets vulnerable to coastal climate change is outlined in Table 14.

Land Use and Buildings

Moss Landing Village

Flood waters in the commercial area (Moss Landing Road) are projected to be higher due to increased storm surge and higher tides pushing more water into the harbor and possibly over the Sandholdt Road sand spit. Buildings within the commercial area at elevations that do not flood today will be affected by wave induced flooding and frequent flooding due to rising tides by 2060. Much of this area will also be at risk to fluvial flooding by 2030. Some of the buildings impacted in this area include the post office, North Monterey County Unified School District Office, and the wastewater pump building, as well as many commercial buildings.

Heights Residential Area

Ten buildings on the southwest corner of the Potrero Road Residential Area are at risk to flooding primarily from coastal storm flooding beginning in 2030.

Moss Landing Island

Risks from increased wave run-up energy and overtopping of the Moss Landing Island leave the harbor vulnerable to catastrophic winter storms. Buildings on the coastal side of Moss Landing Island are at risk from erosion and coastal storm flooding beginning in 2030. MBARI and the MLML Shore Lab have coastal armoring in place that will protect them from erosion through 2030, but by 2060 these structures are predicted to not function as designed and the buildings will be at risk. Flooding from the harbor side due to rising tides and increased river discharge will impact many of these buildings on the Island. Many of the buildings on the Island are also projected to be vulnerable to river flooding by 2060, as fluvial inputs from the Reclamation Ditch drain into the harbor. A few of the buildings on the harbor side of the Island will be further impacted by 2060 from rising tides. By 2100 most of the Island will be at risk from frequent tidal flooding.

Monterey Dunes Colony

Structures within the Monterey Dunes Colony are vulnerable to coastal storm flooding and coastal erosion in 2060. By 2100, 88% of the structures are projected to be vulnerable to erosion.

Harbor

Harbors, by design, locate terrestrial infrastructure and amenities directly adjacent to the aquatic environment. As sea levels rise, these amenities will become less useful as flooding reduces harbor functions during specific climatic conditions (storms, high tides). Some harbor infrastructure may risk the release of hazardous materials when flooded, posing secondary risks to the local environment.

Moss Landing Power Plant

The Moss Landing electric generation facility (owned by Dynegy Moss Landing LLC) is one of the largest natural gas generators on the West Coast. The foot print of the facility is above all projected flooding and erosion hazards, except for the cooling water intake system located on the east bank of the harbor. These intakes will most likely be compromised if wave overtopping of Moss Landing Island (causing sedimentation of the harbor) is allowed to occur.

The number of buildings projected to be impacted by the different coastal hazards at each planning horizon is shown in Figure 20.

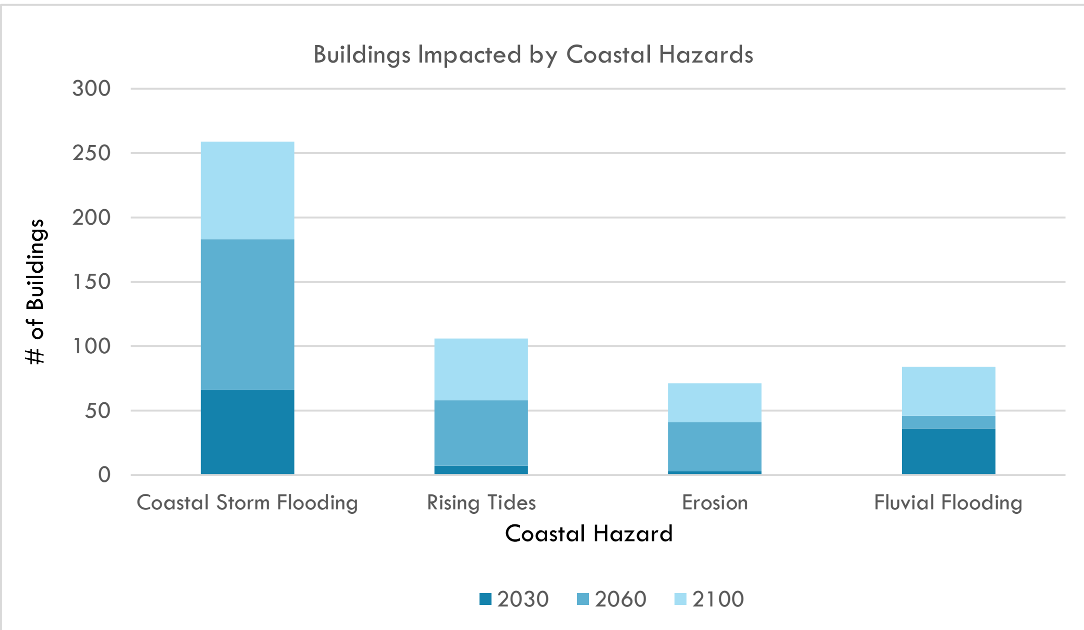


Figure 20. Buildings vulnerable to by different coastal hazards at each planning horizon.

Agriculture within the lower Salinas Valley

As many as 15,293 acres of agricultural land within the lower Salinas Valley (i.e. Moss Landing study area) are less than 10ft above the current mean sea level elevation, making them extremely vulnerable to the combined hazards of sea level rise, increased fluvial discharges and coastal wave induced flooding (Image 2). By 2030 1,272 acres of agriculture land are at risk of periodical flooding during winter rain events. This risk increases to 1,852 acres by 2060 and to 2,565 acres by 2100. By 2030, 92 acres of these agriculture fields will be routinely flooded as higher tides reduce discharge capacity of the tide gates leading to an increase in base water elevation in these drainages. By 2060, coastal structures that protect the Salinas Valley from winter wave induced flooding are predicted to fail and dune erosion along several portions of the Salinas River State Beach will lead to wave overtopping, flooding the Salinas Valley. The risk of flooding due to rising tides for farmland increases to 1,572 acres by 2060 assuming that tide gates no longer function as intended. By 2100, much of the agricultural operations west of Highway One will be flooded during monthly high tides (Figure 21).

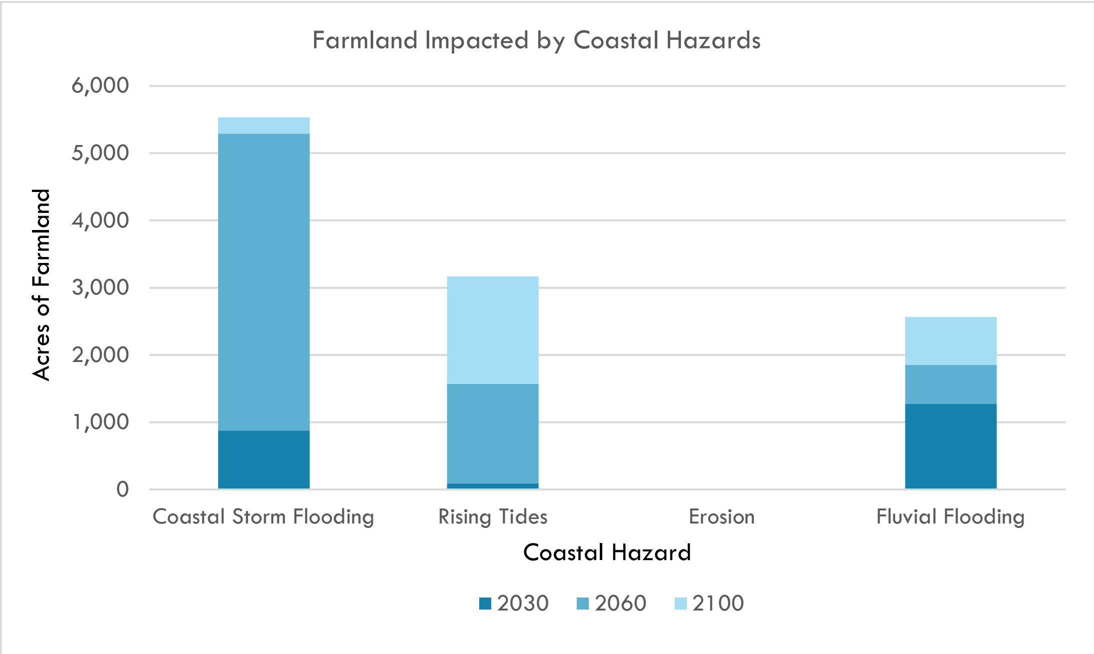


Figure 21. Farmland vulnerable to different coastal hazards at each planning horizon.

Image 2. Flooded agriculture fields in north Monterey County on Saturday, Feb. 18, 2017 after a winter storm. (Photo: Vern Fisher - Monterey Herald)

Transportation

Roads

Figure 22 documents the areas where roads are vulnerable to the combined impacts of coastal climate change and Table 13 lists roads that are vulnerable to the specific hazards and their impact threshold. By 2030, approximately 20,000 feet of roads in the Moss Landing area are vulnerable to periodic flooding during coastal storm events. These include highways, access roads, and residential roads; all prone to increased flood damages as floods become more frequent and severe. Much of Highway 1 between Bennett Slough (north and south of the Elkhorn Slough Bridge) and the Moro Cojo Slough is vulnerable to coastal flooding, as is Moss Landing Road, and portions of Dolan Road, Sandholdt Road and Jetty Road. Parts of Highway 183 south of Castroville are vulnerable to flooding, as is Highway 156 between the Tembladero Slough and Merritt St. Feet of road projected to be impacted by the different coastal hazards at each planning horizon is shown in Figure 22.

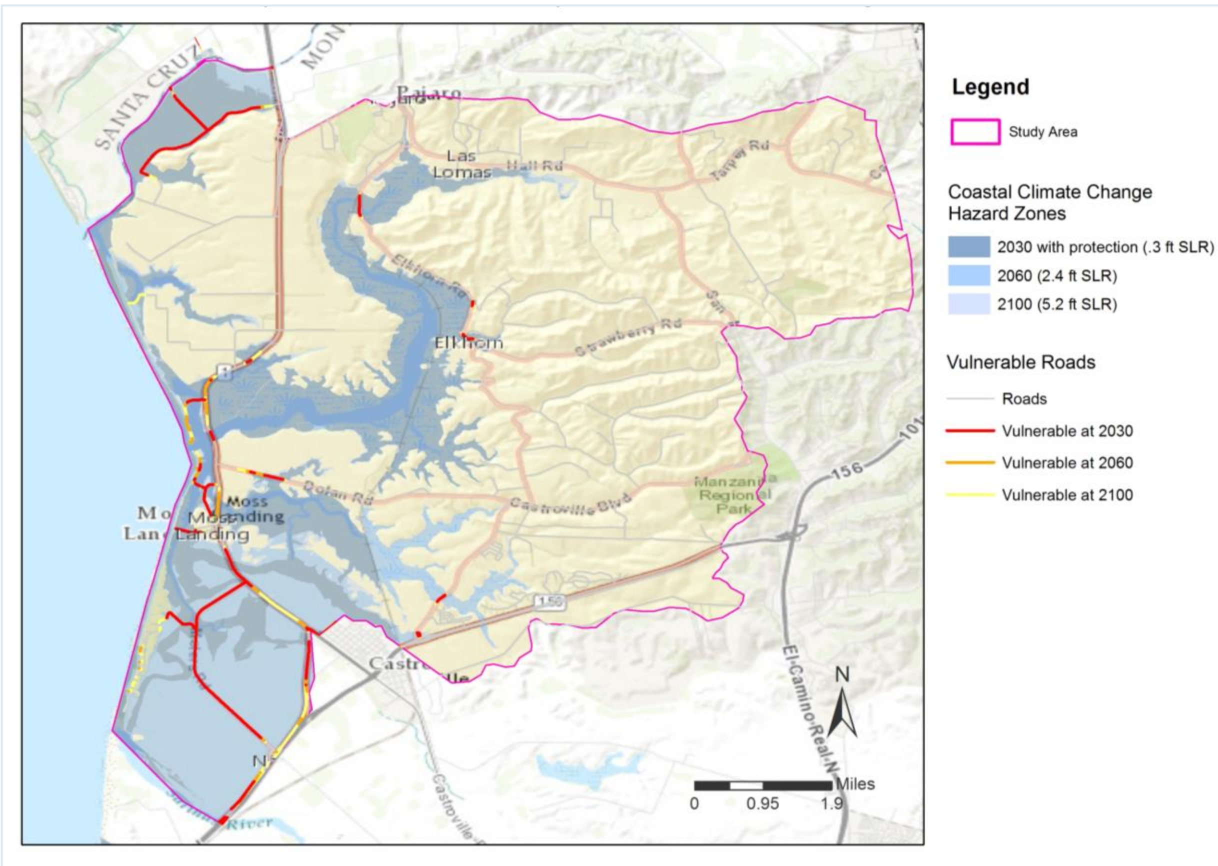


Figure 22. Locations of roadway vulnerable to coastal climate change hazards

Table 13. List of streets vulnerable to each of the hazards at earliest projected time horizon

STREET AND LOCATION	COASTAL STORM FLOODING	EROSION	FLUVIAL	RISING TIDES
Castroville Blvd. over Moro Cojo Slough				2030
Dolan Rd. by Moro Cojo Slough	2060		2030	2030
Elkhorn Rd. over Elkhorn Slough	2060			
Giberson Rd. by McClusky Slough/Zmudowski beach parking	2060			2100
Hwy 1 between Struve Rd. and Jetty Rd.				2060
Hwy 1 along Moss Landing	2060		2060	2100
Hwy 1 and Artichoke Rd over Salinas River	2060			2030
Hwy 1 between Jetty Rd and Elkhorn Slough				2100
Hwy 1 over Bennet Slough between Jetty Rd and Struve Rd	2060			
Hwy 1 over Bennet Slough between Struve Rd	2060			
Hwy 1 over Elkhorn Slough	2060			2030
Hwy 1 over Moro Cojo Slough			2060	
Hwy 1 over Tembladero Slough			2030	2030
Hwy 1 Between Moss Landing and Castroville	2060			2060
Jetty Rd. along sand spit		2060		2060
Jetty Rd. from Hwy 1 to Beach	2060			
Jetty Rd. over Bennet Slough				2060
Laguna Pl.	2060			
Mc Gowan Rd.	2060			
Molera Rd. (all)	2060			
Molera Rd. over Tembladero			2030	2030
Monterey Dunes Way	2060			2100
Monterey Dunes Way over Old Salinas River Channel			2060	
Moss Landing Rd. along Moss Landing Village			2030	2030
Moss Landing Rd. from Whole Enchilada/Hwy 1 intersection	2060			
Moss Landing Rd. over Old Salinas River			2030	
Potrero Rd. (all)	2060			
Potrero Rd. next to Salinas River State Beach parking lot				2100
Potrero Rd. over Old Salinas River Channel			2030	2030
Sandholdt Rd. along Moss Landing Island	2060	2100	2030	2060
Sandholdt Rd. over Old Salinas River Channel	2060			2030
Trafton Rd.	2060			
Whale Way next to Phil's Fish Market	2060	2060		2100

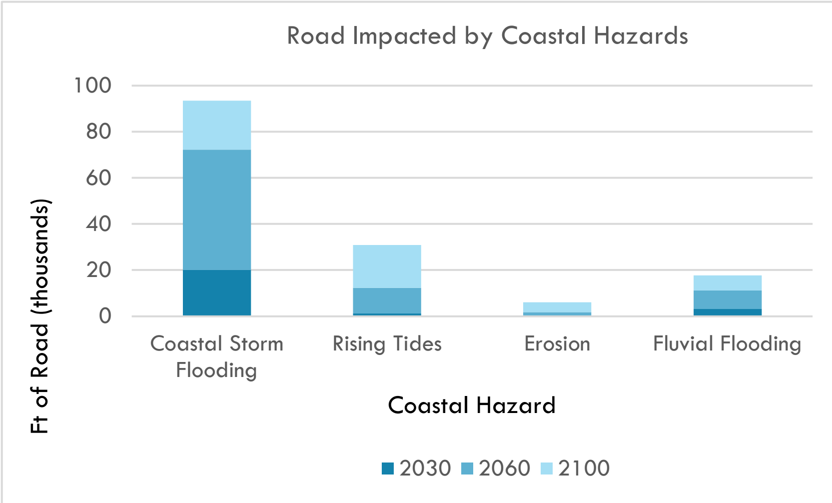


Figure 23. Feet of road vulnerable to different coastal hazards at each planning horizon.

Rail

Large portions of the rail line are already vulnerable to rising tides (Image 3). A total of 12,636 feet rail line is vulnerable by 2060 and 21,072 feet of tracks is vulnerable by 2100 if the rail line is not raised within Parsons Slough, Moro Cojo Slough and south of Castroville.

Image 3. Jan 1, 2014 King Tide pours over the railroad tracks between Kirby Park and the Elkhorn Research Reserve
(Photo: Fred Hochstaedter)

Recreation and Public Access

The Salinas River and Moss Landing State Beaches provide unique and invaluable recreation and coastal access opportunities within the central Monterey Bay. These beaches are vulnerable to increased wave intensity during winter storms. There are 17 designated coastal access locations within the Moss Landing area. By 2060, as many as 10 coastal access locations along the Moss Landing coast line will be severely impacted by Coastal Climate Change (Figure 24). Erosion will specifically impact beach access along Jetty Road and Sandholdt Road. More than five acres of coastal access parking are projected to flood from storm surge by 2060. Access to the harbor will be compromised during winter storms. High tides will regularly flood parks and open space around the Elkhorn Slough. Coastal access will be restricted due to flooded roads.

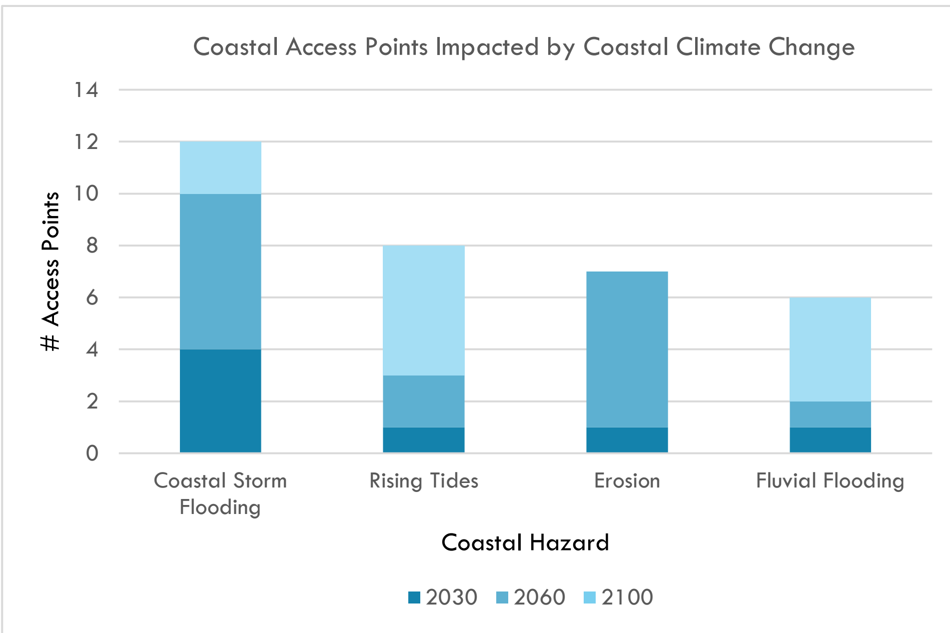


Figure 24. Number of coastal access points vulnerable to different coastal hazards at each planning horizon (N=17).

Water and Utilities

By 2060, both the Potrero and Moss Landing tide gates service capacity will be reduced during winter storms, likely leading to inland flooding. Monterey County Water Resources Agency has studied replacing both tide gate systems to restore proper function. The design will likely not be sufficient to manage all predicted flooding. Monterey County Water Resources Agency is considering pumps and other mechanisms to help protect property and infrastructure.

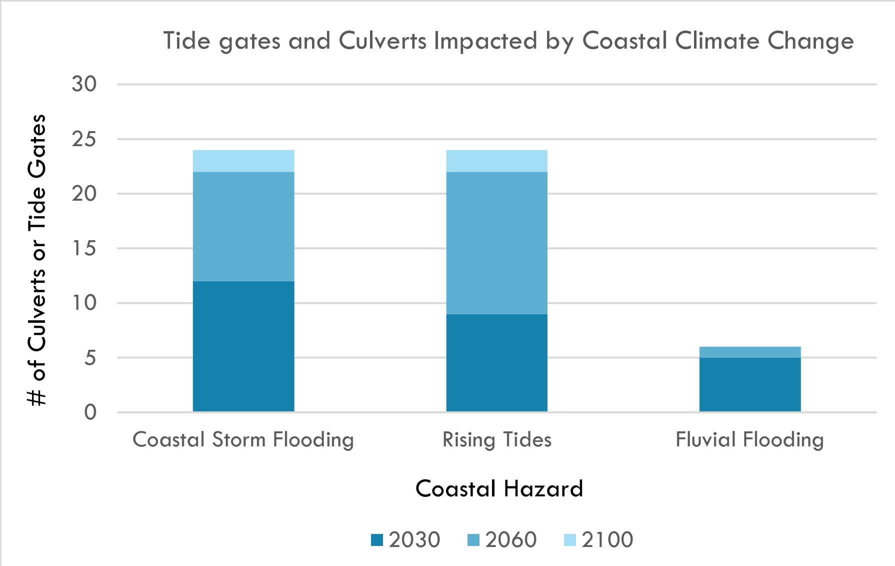


Figure 25. Tide gates and culverts vulnerable to different coastal hazards at each planning horizon.

Four culverts and control structures in Bennett Slough, 11 control structures in Elkhorn Slough, 3 control structures in Moro Cojo Slough and 4 structures in the Old Salinas River /Tembladero are vulnerable to projected increases in storm intensity leading to periodic flooding (Figure 25). Electrical and phone utility data were not available for this analysis.

Natural Resources

Wetlands

The Moss Landing and Elkhorn Slough areas support significant high-quality wetland and upland ecosystems. These natural areas are vulnerable to an increase in the frequency and elevation of flooding. Higher tides will also increase salt water inundation to brackish and fresh water wetlands. The North Monterey County LCP identifies and maps these wetlands and creeks as Environmentally Sensitive Habitat Area (ESHA). Much of the designated ESHA is vulnerable to 2060 impacts of Coastal Climate Change.

Nearly all of the wetlands in Moss Landing are within the coastal storm flood zone for 2030 (80%), and by 2100, 86% are vulnerable to rising tides. Some of these wetland areas, particularly in Elkhorn Slough, are designated critical habitat. All of the Moro Cojo and OSR wetlands are within the boundaries of the 2030 ESA hazard maps. Current tide gate infrastructure will likely not be able to fully mitigate the combined impacts of higher tides, storm surge and increased rain fall and river discharge. Some historical wetland areas that have been reclaimed for farming will become vulnerable to greater flooding in the future and may providing restoration opportunities for agencies in partnership with land owners.

Sand Dunes

The 2030 erosion hazard map extends inland past the eastern edge of the dunes. Breaks in the dunes between Jetty and Potrero roads will reduce the protection this dune provides the harbor from winter storms. Projected breaks within the dunes south of the Potrero tide gates will leave much of the Salinas Valley vulnerable to Coastal Flooding (Figure 18).

The dunes directly north of the Salinas River mouth are especially narrow, and thus, already prone to winter storm erosion and wave overtopping. The dunes have also been eroded by the Salinas River as it flows northward to the ocean. These dunes are vulnerable to erosion and are at risk of breaching during winter storms before 2060. Some rip-rap currently restricts erosion along this portion of the coast but is likely insufficient to resist the projected wave energy and height of 2060 storms. Nearly all of the beaches are projected to erode by 2060, if the beaches and dunes are not allowed to migrate inland. Figure 26 shows the cumulative number of acres of dune that are projected to be eroded by each time horizon.

Jetty Road Sand Spit

By 2030, dune erosion is projected to extend inland, reaching jetty road in one location. By 2060, much of Jetty Road is vulnerable to erosion and unless the dunes are encouraged to migrate inland, north harbor will be vulnerable to the secondary consequences of wave impacts due to the loss of the protective dunes. By 2100, coastal erosion will lead to the loss of much of Jetty Road sand spit, dune habitat and threaten north harbor (Figure 18).

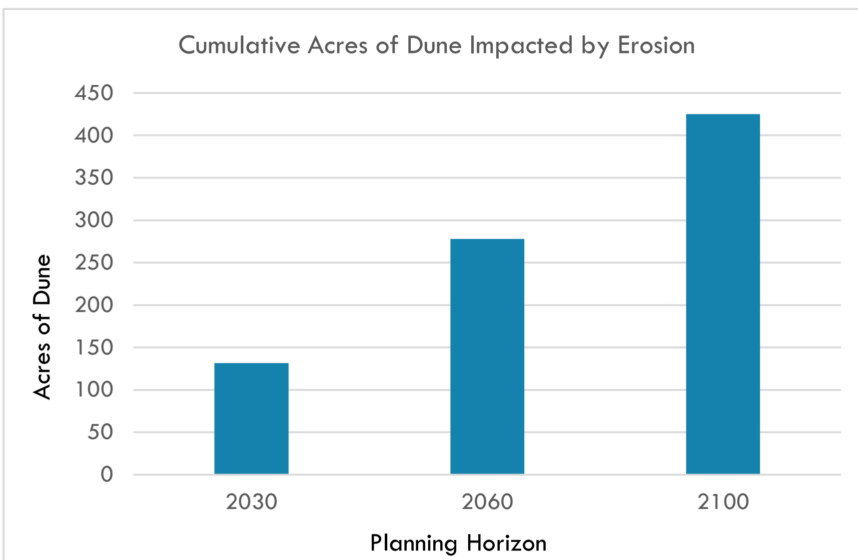


Figure 26. Cumulative acres of dunes within the Study Area vulnerable to coastal erosion

Table 14. Specific assets vulnerable to coastal climate change hazards in the Moss Landing area.

ASSET	COASTAL HAZARD	EARLIEST IMPACT
Potrero Rd Residential Neighborhood	Coastal Storm Flooding	2030
Moss Landing Island/Sandholdt Road Buildings	Erosion Coastal Storm Flooding Rising Tides Fluvial Flooding	2030[23] 2030 2100 2060
Whole Enchilada Complex	Rising Tides Fluvial Flooding	2060 2030
Moss Landing Village	Coastal Storm Flooding Rising Tides Fluvial Flooding	2060 2060 2030
Monterey Dunes Colony	Erosion Coastal Storm Flooding	2060 2100
Moss Landing State Beach	Erosion Coastal Storm Flooding	2030 2060
Salinas River State Beach	Erosion Coastal Storm Flooding	2030 2060
Farmland	Coastal Storm Flooding Rising Tides Fluvial Flooding	2030 2060 2060
Highway 1	Coastal Storm Flooding Rising Tides Fluvial Flooding	2030 2030 2030
Coastal Access Ways	Erosion Coastal Storm Flooding Rising Tides	2100 2060 2060
Potrero Rd and Moss Landing Rd tide gates	Coastal Flooding Rising Tides Fluvial Flooding	2060 2060 2030
Moss Landing Harbor	Coastal Flooding Fluvial Flooding Erosion Rising Tides	2030 2060 2060 2100

[23] MBARI and MLML are projected to be protected through 2030 by the existing coastal armoring.

6. Economic Impacts of Future Climate Risks

Costs of emergency response

The Monterey County Hazard Mitigation Plan reports that more than 800 flood claims have been paid by FEMA within the unincorporated county for more than $21 million dollars. The County plan estimates 4800 residential and 600 commercial properties are vulnerable to flooding within the entire county. Our study identified additional properties that are vulnerable to flooding associated with coastal climate change that may expand those potential losses.

Property valuation

A simple property loss calculation was completed to provide rough estimates of the cumulative costs of the projected risks for each time horizon. Costs for residential and commercial properties were estimated using average values reported within the County Hazard Mitigation Plan[24]. These estimates were used to quantify the cumulative property loss valuation and the economic impact of replacing at risk buildings, infrastructure and services (Table 15).

Municipal Replacement Costs of critical infrastructure

For municipal buildings and infrastructure, the Monterey County Hazard Mitigation Plan identifies costs to replace or move general categories of infrastructure found to be at risk of various natural hazards (not including property costs to relocate). These average values were used for this analysis.

Approximately $85 million in public, private and commercial properties are at risk by 2030 from the combined hazards of coastal climate change. Most of these properties are at risk of winter flooding. An additional $100 million in agriculture properties are at risk of flooding as well, even accounting for tide gate protections. In total, $184 million in properties and infrastructure are within the combined hazard areas projected for 2030. These estimates use the total property value (assuming total property loss) rather than the projected damage to structures and crops. Estimated damage would be far greater if the two tide gate structures did not reduce ocean derived storm flooding.

By 2060 the value of property and infrastructure within the hazard area increases to almost one half billion dollars. The significant increase is due mostly to the increase in the vulnerability of the Salinas Valley are no longer protected by the tide gates. During each time horizon, half the total property

[24] Monterey County Multi-Jurisdictional Hazard Mitigation Plan, 2014, Table 5-1

vulnerable to climate change is for agriculture lands (not accounting for agriculture inland of the coastal zone boundary).

Table 15. Total Value (2016 dollars) of Major Infrastructure at Risk

ASSET	UNITS	2030 (WITH PROTECTION)	2060 (NO PROTECTION)	2100 (NO PROTECTION)
Buildings				
Residential	property value	$8,925,000	$30,975,000	$59,325,000
Commercial	property value	$17,057,808	$19,104,745	$21,833,994
Public	replacement cost	$27,500,000	$56,500,000	$64,500,000
Agriculture	property value	$99,550,000	$264,500,000	$276,600,000
Property losses		*$153,032,808*	*$371,079,745*	*$422,258,994*
Transportation				
Roads	replacement cost	$31,397,838	$113,468,215	$147,527,568
Rail	replacement cost	$2,199,400	$4,452,280	$6,923,840
Highway 1	replacement cost	$868,362	$5,079,940	$6,475,920
Transportation losses		*$34,465,600*	*$123,000,435*	*$160,927,328*
Water and Utility Infrastructure				
Storm Drain Structures	relocate and replacement cost	$0	$107,955	$185,682
Combined losses		***$187,498,407***	***$494,188,134***	***$583,372,004***

Costs = $5.7mill per mile for storm and sewer; $280 per linear foot for roads, $525,000 replacement cost for residential and $680,000 for commercial properties, farmland valued at $50,000 per acre.

Similar property valuations were estimated within the 2016 report by The Nature Conservancy. The TNC report estimated that $160 million in properties and infrastructure would be vulnerable within this area by 2030 (excluding agriculture, our estimate of at risk properties is $90 million) and TNC estimates $260 vulnerable by 2100 and this study estimates approximately $300 excluding agriculture. The TNC report also provides an estimate cost of coastal armoring and of the valuation of coastal beach and wetland habitat (attributed to tourism economy).

In this report, we have focused on understanding if and how existing protective structures can provide the anticipated protection against coastal erosion and fluvial flooding. This analysis finds that the hazards projected for 2100 within the Moss Landing community and the lower Salinas Valley are so severe and necessary adaptation measures will be so significant, that economic valuations of natural habitat and real property, as well as cost comparisons among various adaptation options will likely not reflect future values or future economic realities.

7. Adaptation

7.1 Adaptation Strategy Selection

The risks associated with each of the modeled coastal processes (wave run-up and overtopping, coastal erosion, rising tides and fluvial flooding) threaten various coastal infrastructure differently. Selection of adaptation options must be driven by the possible damage of each risk and the frequency of reoccurring impact. Wave and river flooding can damage buildings and agricultural crops, temporarily restrict use of public amenities, make storm drains ineffective and limit the use of roads, parking lots and walkways. Storm flood risks represent periodic impacts and responses to these threats may be lower in cost and can often be temporary.

Dune and beach erosion and flooding during high tides, are permanent or reoccurring impacts that can lead to a complete loss of infrastructure and use of those properties. Such losses will require extensive rebuilding or reinforcement, a change in use of the property, or abandonment of the property.

Future investments in the protection of coastal structures will need to be weighed by County staff and private property owners against factors including the structure's replacement costs, limitations provided by regulatory agencies, and expected longevity and effectiveness of the adaptation strategy selected. Secondary implications of adaptation options including impedances to coastal access, loss of beach and impacts to the beauty of the coastline should also be considered. This analysis highlights the need for long-range coastal management planning that sets policies that best balance property value with costs of adaptation and the resulting changes to the public coastline and wetland resources that will occur.

7.2 Recommended Actions within Local Plans

Moss Landing Community Plan

The current version of the Moss Landing Community Plan briefly discusses sea level rise, but does not discuss what adaptation measures Moss Landing can or should take. An objective of this SLR vulnerability report is to provide additional information on future risks and possible adaptation strategies to address the future hazards this community is projected to face.

Hazard Mitigation Plan (2014)

The Multi-Jurisdiction Hazard Mitigation Plan identifies "the primary goal of all local governments is to promote the public health, safety, and welfare of its citizens." The plan identifies six goal statements for local hazard mitigation planning in Monterey County (Table 16).

Table 16. Goals for local hazard mitigation from the Monterey County Hazard Mitigation Plan

GOAL	DESCRIPTION
Goal #1	Promote disaster-resistance and ***climate adaptation*** strategies in ***future development***.
Goal #2	Retrofit, reinforce, or otherwise protect ***existing community assets***, especially ***critical infrastructure***, for hazard resilience.
Goal #3	Encourage ***natural systems protection*** through plans and policies; vegetation, debris and sediment control measures; maintenance and restoration programs; ecosystem services; and other activities for areas such as the Salinas and Carmel rivers and the Monterey County coast.
Goal #4	Provide ***regulatory tools*** for applicable hazards and integrate hazard mitigation principles into appropriate ***local plans*** such as the General Plan during the next General Plan update.
Goal #5	Increase ***public education and awareness*** on hazard risks and available mitigation techniques for reducing hazard risk; build and support ***personal preparedness*** to enable the public to better prepare for, respond to, and recover from disasters.
Goal #6	Improve ***local government capacity*** for disaster resiliency; facilitate ***coordination*** between participating jurisdictions and state and federal agencies, local utility companies, local businesses, non-profit organizations, and other stakeholders to promote hazard risk reduction.

7.3 Strategies Discussed in Related Studies

Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay

In a 2016 study[25], The Nature Conservancy (TNC) compared the costs and benefits of allowing coastal erosion to occur within Moss Landing. This strategy allows the beaches and coastal ecosystems to retreat naturally, in contrast to increased shoreline armoring along much of the Salinas State Beach. The report concludes that because of the high cost of the armoring, the economic benefits of allowing erosion are greater than armoring the shoreline, despite property losses. The study reported that by 2100, the difference in net present value of local infrastructure is $1.1 billion when comparing adaptation strategies with and without armoring. TNC also analyzed the costs and benefits of allowing erosion to occur through use of conservation easements and found that the conservation easements have a significantly higher net present value than allowing the landowners to bear the costs of adaptation. Successful implementation of a coastal adaptation easement program will rely on an NGO or government agency to purchase the land from private landowners.

[25] Leo et al. 2016. *Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay.* pg. 62-63

Natural Infrastructure

Partners at the Center for Ocean Solutions (COS) at Stanford University have completed two studies to evaluate the natural capacity of Moss Landing wetlands and dune ecosystems to mitigate risks of climate change on inland resources (Figure 27)[26]. The 2016 report by COS suggests: "If these habitats are lost, degraded or unable to adapt by migrating inland, then local communities also lose beneficial services they provide which include: sequestering carbon, improving water quality, buffering ocean chemistry, providing nursery or nesting grounds, and protecting from erosion and inundation." Two key findings of the COS report for Moss Landing are:

- Built structures—including some coastal dependent structures—limit adaptation options for parts of Moss Landing. Critical infrastructure such as the Moss Landing power plant, harbor, and Highway 1 all present challenges to implementing many otherwise viable strategies.
- Nature-based climate adaptation options in the Moss Landing case study area include restoration or preservation of dune and wetland habitats. In addition, nourishing beachfront locations with additional sediment is an option if appropriate environmental concerns are addressed.

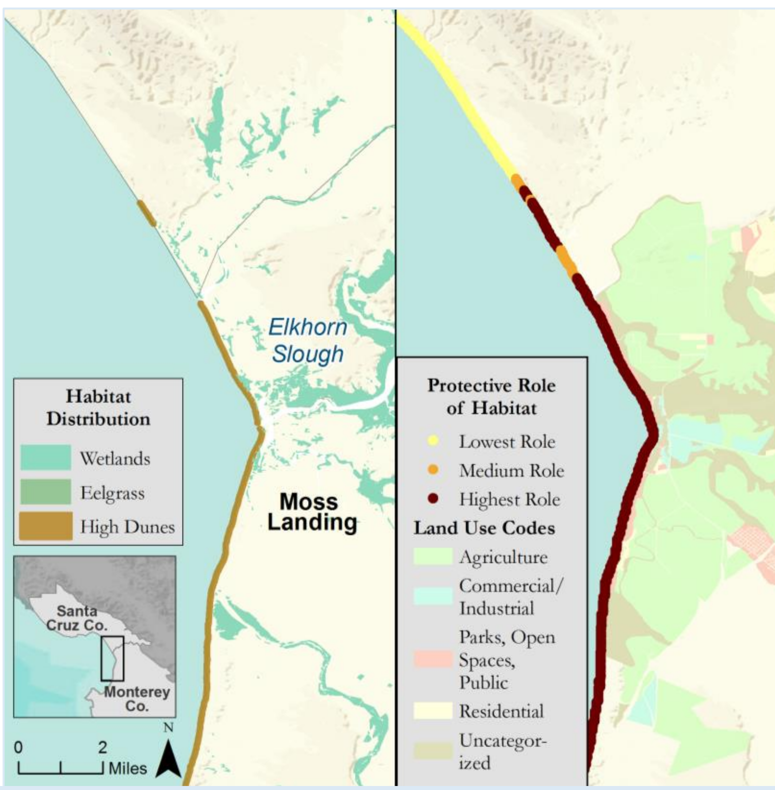


Figure 27. Protective role of habitat in Moss Landing
(Figure source: COS, 2016)

[26] Center for Ocean Solutions. 2016. *Coastal Adaptation Policy Assessment: Monterey Bay*

STATE GUIDANCE

The Coastal Act allows for protection of certain existing structures. However, armoring can pose significant impacts to coastal resources.

To minimize impacts, innovative, cutting-edge solutions will be needed, such as the use of living shorelines to protect existing infrastructure, restrictions on redevelopment of properties in hazardous areas, managed retreat, partnerships with land trust organizations to convert at risk areas to open space, or transfer of development rights programs. Strategies tailored to the specific needs of each community should be evaluated for resulting impacts to coastal resources, and should be developed through a public process, in close consultation with the Coastal Commission and in line with the Coastal Act.

Coastal Commission support of Cities that update their Local Coastal Plans to include the adaptation measures prioritized by the community can aid successful implementation of a community's adaptation strategy

Example of adaptive dune restoration activities to increase the resiliency of foredunes to wave impacts. (Photo: R. Clark)

7.4 Current Strategies Used within Moss Landing

The Moss Landing community currently uses several adaptation and protection strategies to minimize risks of flooding and coastal erosion. Most of the properties on the Moss Landing Island have enhanced the dune plant community in front of their buildings to increase dune height and stability. To reduce flooding of properties from water within the Old Salinas River, a berm has been constructed on the west side of Moss Landing Road. Monterey County also manages a complex system of tide gates and lift stations to lower water levels within the lower Salinas Valley. Monterey Water Resources Agency actively maintains this infrastructure during storm events to ensure they work properly. Monterey County also manages the Salinas River lagoon by releasing water to the Old Salinas River and by breaching the mouth when water elevations pose flood hazards (greater than 5 ft.).

7.5 Moss Landing Climate Adaptation Strategy Options

Numerous reports have compiled lists of adaptation options and describe their use in addressing different climate risks (
Table 17). Examples of climate adaptation strategies being applied to address local hazards are only just becoming available (see Marin Ocean Coast SLR Vulnerability Assessment[27]). Information on the costs of these strategies is limited but examples of most strategies exist and can provide a range of costs[28]. Local public works departments are best able to estimate the true costs of various construction projects and municipal planners, NGOs and consultants continue to evaluate the feasibility and efficacy of planning and regulatory options. Numerous planning documents exist that provide narrative description of each adaptation option[29].

2017-2030 Adaptation Options

Conditional Rebuilding Restrictions

Impose restrictions on reconstructing buildings that may be damaged by projected hazards. These restrictions can include adhering to stricter codes or more resilient designs, or rebuilding only under the agreement to not armor in the future. Options for Moss Landing hazards include:

- **Adopt policies to limit municipal capital improvements that would be at risk**

  Prudent adaptive management to climate change begins with not placing new municipal infrastructure at risk to future hazards. County policies that establish review processes for proposed Capital Improvement Projects located within future hazard zones have been adopted by the City of San Francisco (http://onesanfrancisco.org/wp-content/uploads/Guidance-for-Incorporating-Sea-Level-Rise-into-Capital-Planning1.pdf). These guidelines help staff to review proposed infrastructure projects to ensure that those projects will not become vulnerable to projected climate risks within the expected lifespan of the project.

[27] Sea-Level Marin: Adaptation Response Team and Marin County Community Development Agency. 2015. *Marin Ocean Coast Sea Level Rise Vulnerability Assessment, Draft Report*

[28] ESA PWA. 2012. *Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay.*

[29] Grannis, J. 2011. Adaptation Tool Kit: Sea Level Rise and Coastal Land Use

Table 17. List of Adaptation Strategies (short= 0-5 years, med= 5-30 years, long= 30+ years)

TYPE	DURATION OF PROTECTION	RIVER FLOODING	COASTAL STORM FLOODING	EROSION	WAVE IMPACTS	RISING TIDES
Hard						
Levee	medium	•	•			•
Seawall or Revetment	medium		•	•	•	
Tidal Gate	medium		•			•
Flood wall	medium	•	•			•
Groin	medium		•	•	•	
Soft						
Wetland shoreline	medium		•		•	
Dune restoration	medium		•	•	•	•
Beach Nourishment	short		•		•	
Offshore structure	medium		•		•	
Accommodate						
Elevate	medium	•	•			
Managed Retreat						
Retreat	long	•	•	•	•	•
Rolling easement	long	•	•	•	•	•
Strict land use re-zone	long	•	•	•	•	•
Regulatory Tools						
Stricter Zoning	long	•	•	•	•	•
Floodplain Regulations	long	•	•		•	•
Building Codes and Resilient Designs	long	•	•		•	•
Setbacks/Buffers	long	•	•	•	•	•
Rebuilding Restrictions	long	•	•	•	•	•
Planning Tools						
Comprehensive Plan	long	•	•	•	•	•

- **Zoning**

  The Moss Landing Community Plan is being drafted and can be a useful document to establish future adaptation options. Rezoning areas that are at risk of future flooding for uses that can accommodate these temporal impacts can minimize repair costs while retaining the economic use of these properties. Rezoning commercial and residential properties within the 2030 hazard areas to more resilient uses can help to reduce future property loss and protect coastal access and recreation from coastal squeeze while helping high risk properties retain property value. Rezoning areas for commercial use further inland (i.e. transferable development credits) may enable the community to migrate inland with the coast.

- **Elevate**

  Raising buildings above 2030 flood may be a cost-effective midterm adaptation strategy. As tidal flooding becomes common, however, use of these buildings may once again be compromised.

- **Setbacks and Buffers**

  Adopting setbacks and buffers helps ensure that no building occurs too close to projected hazard areas and will allow for the shoreline to retreat naturally.[30] Establishing setbacks for future development on the Moss Landing Island will reduce future loss of beach, limit building obstructions to lateral access and increase the useful life of these buildings. Placing required parking near future hazards (shoreward) may help establish buffers that can be incrementally abandon as coastal erosion encroaches on these properties.

Prioritize coastal protection structures for upgrade or removal

There are a number of developments on the Moss Landing Island sand spit that are vulnerable to coastal erosion by 2030. To increase near term resiliency of the island, the County may consider adopting a combination of strategies including allowing existing hard armoring to be maintained to protect current buildings, the adoption of new building guidelines for future development to be placed outside the 2030 hazard zone and designed to be resilient to future hazards and support of efforts to maintain beach elevation and width to provide for a more resilient demarcation between beach and buildings.

- **Investigate beach nourishment and Groins to maintain Moss Landing island beach width**

  A groin is a structure perpendicular, rather than parallel, to the coastline, extending from the beach to the sea. On long beaches, many groins can help distribute sand more evenly and reduce erosion. These structures however can also contribute to new erosion patterns and new wave patterns. Construction of a groin in concert with harbor derived beach nourishment may increase beach width along the Island, especially where current buildings are encroaching on public beach. The offshore submarine canyons may compromise the effectiveness of this strategy and additional sediment transport studies are warranted.

[30] Grannis, J. 2011. Adaptation Tool Kit: Sea Level Rise and Coastal Land Use

Beaches are a key natural buffer as well as a popular human asset. Beach nourishment involves bringing sand from elsewhere and depositing it on the beach in order to restore the eroded beach. Beach nourishment can maintain the use-value of a beach and can help protect infrastructure beyond the beach from erosion and flooding. However, it is a temporary and costly solution that changes the profile of the natural beach and shoreline, and the new sand (usually a different grain size) often erodes quicker than the natural sand. And, like any human process that disturbs nature's processes, beach nourishment can damage local ecosystems and species.

- **Dune Restoration**

  Dunes are critical in acting as a buffer between the ocean and the areas behind the dunes, just like seawalls, except because dunes are natural, they also preserve existing ecosystems and have the ability to move inland with the beach and the sea level in order to preserve the whole beach-dune system. Dune restoration involves removing non-native plants in favor of native species, which allow the dune to migrate and provide a home for other native species.

  CCWG staff has worked with the State Coastal Conservancy and California State Parks to begin native plant rehabilitation of key sections of the Salinas River State Beach and will be completing long term monitoring of this project to document the success of these soft/natural adaptation strategies in coming years. Such dune enhancement and restoration efforts may be a valuable short to medium term adaptation strategy. If these dunes are allowed to migrate inland (leading to the loss of agricultural lands), they may continue to provide protection from ocean flooding.

Reduce risks of flooding

The periodic flooding projected within the 2030 hazard maps can be planned for. Actions to protect and accommodate projected flooding can reduce risks to those properties.

- **Upgrade the flood berm along Moss Landing Road**

  A small berm has been constructed between the Old Salinas River and buildings along Moss Landing Road. The berm does not appear to be uniformly designed or constructed but does provide a first line of protection from high waters within the Old Salinas River. Upgrading this berm may be a cost-effective way to help reduce risks of coastal flooding risks projected for the Moss Landing Commercial area through 2030.

- **Evaluate Tide Gate upgrades to improve flood release**

  Through the 2030 planning horizon, the Moss Landing and Potrero tide gates are predicted to continue to serve an important protection from tidal flooding to upstream properties, primarily agriculture and natural habitats. The tide gates however have restricted discharge from these two watersheds during large rain events which have exacerbated flooding up stream. Upgrades to these gates that allow overflow during large events may help to reduce flooding extent and duration of flooding along upstream farmlands.

- **Establish Managed Retreat policies to support future adaptation**

  Managed retreat is an adaptation strategy aimed to facilitate and regulate the gradual move away from areas vulnerable to flooding or erosion. Managed retreat can take many forms, including zoning, setbacks, buffers, restrictions, rolling easements, and land acquisition. These strategies can be used in conjunction with other adaptation measures to facilitate the most fluid and equitable adaptation approach to the varying threats that sea level rise poses. Managed retreat programs can work in tandem with other adaptation strategies to reduce impacts of flooding, maintain local character, improve natural habitat areas and secure coastal access.

- **Improve flood attenuation through Creek and Wetland Restoration**

  Wetlands can act as a critical buffer from waves, tides, and erosion and they will transition inland as the sea level rises if they are given the space to do so. Additionally, wetlands provide natural pollution filtration and shoreline stability, sequester carbon, and can attenuate flood waters, along with providing important habitat that supports local fishing and tourism. Numerous Wetland restoration efforts are underway within the Elkhorn and Moro Cojo sloughs. The County and local community can support these activities and ensure that future designs help improve climate resiliency of the Moss Landing community.

  The Greater Monterey Integrated Regional Water Management Plan outlines strategies to improve the function of local drainages to benefit the goals of numerous stakeholders. Proposed watershed management and drainage enhancement projects within the IRWM plan can help the lower Salinas Valley become more resilient to predicted increases in flooding during rain events. Numerous low-lying areas along these drainages (notably Carr Lake) can be acquired and redeveloped to provide aquatic habitat, open space, recreation and flood attenuation and storage that would greatly reduce the predicted negative interactions associated with more intense rain fall and higher seas.

2030-2060 Adaptation Options

Identify areas for future protection accounting for costs, feasibility and secondary impacts

- **Tide gate upgrades**

  By 2060 the ability of the current tide gates to provide protection from coastal and tidal flooding may be significantly reduced due to the projected 12–29 inch increase in water elevations within the harbor. Further analysis with help from the Monterey County Water Resources Agency is necessary to determine the expected reduction in service and the possible increase in water elevation behind the structures. Replacing tide gates with pump stations may increase the capacity of the system to retain current water levels within the Old Salinas River but it will likely be expensive to size and operate a system large enough to manage predicted increases in winter river discharges of up to 700cfs.

The estimated total costs of installing and operating new pumps on one or both tide gate systems should be evaluated in comparison with the benefit to 1,592 acres of farmland at risk of periodic coastal flooding.

- **Hard Armor Protection**

  Hard armoring can be used in areas with high-density development or with critical infrastructure in order to protect existing coastal infrastructure from flooding or erosion. Hard armoring, such as sea walls, tide gates, revetments, dikes, levees, riprap, etc., can be effective in creating a barrier between the land and the sea, and can sometimes be used as a new, elevated surface for parks, walkways, roads, or other public uses.

  However, there are many drawbacks to hard armoring that make it a relatively unsustainable long-term protection measure. The high costs of building, maintaining, and increasing hard armoring over time must be taken into account. Maintaining or upgrading hard armoring means the area between the armoring and the ocean—the beach, dunes or wetlands— has nowhere to migrate as the sea level rises, and so while the hard armoring will protect coastal development, the ecosystem and all its benefits, including its role as a natural barrier, will disappear. Hard armoring can also increase erosion of unprotected neighboring properties through the reflection of wave energy. Additionally, hard armoring allows development in increasingly vulnerable areas, which can result in a larger impact on the community if the armoring fails (such as in New Orleans due to Hurricane Katrina with the failure of the levees).

  Despite the negatives associated with hard armoring, selective use may be one option for areas of Moss Landing. Structures on Moss Landing Island and within the Monterey Dunes Colony are projected to be at risk of coastal erosion by 2060. Strategies should be developed that identify areas where coastal armoring is feasible and appropriate and areas where building retrofits and retreat are more appropriate. These decisions should take into account projected risks from Coastal Climate Change for the total life of the properties being protected. Future risks to the harbor should also be considered.

Identify areas for managed retreat to retain sufficient beach area for recreational use

Protection of all properties and infrastructure identified at risk during each time horizon is likely infeasible. Therefore, The Moss Landing community will need to establish adaptation strategies that best meet local long-term goals. Public cost considerations, longevity of adopted strategies and resultant changes to the community should be considered when setting policy. Establishing equitable managed retreat policies early will likely best enable the long-term implementation of these policies to ensure the long-term sustainability for the community. Selecting time horizons and climate conditions for which next phase adaptation strategies are triggered will allow the community to anticipate and prepare for future actions.

Providing for the managed retreat of the Salinas River dunes complex onto adjacent farm and residential properties may provide significant longer-term protection from river and storm flooding near the Salinas River mouth.

Identify areas for redevelopment and transfer of development credits

To ensure that Moss Landing remains a viable coastal community, areas should be identified where urban redevelopment can occur, safe from projected hazards. Areas of North Harbor, Moss Landing Heights and Dolan neighborhoods are outside of projected hazard zones.

2060-2100 Adaptation Options

Between 2060 and 2100, increased coastal wave damage, greater flooding depths and periodicity and higher tides will threaten significant portions of Moss Landing Island and commercial area properties. Protection of all properties from these risks will be costly, technically challenging and will degrade the communities charm. Decisions regarding what the urban/beach front area will look like in 2100 will need to be made much earlier if adaptation is to be strategic and cost effective. Adopting coastal adaptation and retreat policies once all efforts to protect infrastructure fail is a costly strategy.

Between 2060 and 2100, risks from Coastal Climate Change increase significantly. Much of the Island and commercial district are projected to be flooded during high tides and impacted by winter storms. Highway One and other roads will need to be upgraded or realigned if they are to continue to function. Adaptive community planning can help Caltrans and other agencies make better decisions regarding how to upgrade roads and utilities to best serve the Moss Landing of 2100.

Implement managed retreat strategies

There are a number of theoretical managed retreat strategies that have been described within the literature. Examples of coastal communities adopting re-zoning, building restrictions and other land use policies to drive the removal of buildings and infrastructure from the California coast, however, are few.

EXPLORING ADAPTATION POLICY

The Coastal Commission 2015 Guidance references strategies that include:

> *"restrictions on redevelopment of properties in hazardous areas, managed retreat, partnerships with land trust organizations to convert at risk areas to open space, or transfer of development rights programs"*

The Marin Climate Adaptation effort[31] has completed focus area analysis of coastal communities (i.e. Bolinas) similar to this Moss Landing report and has identified infrastructure that will need to be raised or otherwise modified to respond to tides and coastal flooding. Agriculture lands have been identified for transition to wetlands. No residential or commercial private properties have been identified for removal and no procedures have been identified to support municipalities to *"convert at risk areas to open space."* Such procedures are likely necessary if Moss Landing is to remain a viable community in 2100. The overwhelming hazard projections for this community suggest that long term adaptive planning and managed retreat programs are necessary and should be developed as early as possible (i.e. 2030) for future implementation (i.e.2060-2100).

[31] Sea-Level Marin: Adaptation Response Team and Marin County Community Development Agency. 2015. *Marin Ocean Coast Sea Level Rise Vulnerability Assessment, Draft Report.*

Cost implications from routine impacts of projected hazards will lead many property owners to choose between upgrading their properties to be more resilient or abandon the current uses of those properties. Establishing equitable retreat policies that outline how and when various portions of the community should be relocated will enable the community to adapt and become more resilient.

Cost sharing between private property owners and state and local agencies will need to be defined and local land trusts may play an important role in administering these programs in years to come. Adaptation strategies adopted decades before they are implemented will help property valuation, economic considerations and land use objectives accommodate these future changes.

Realign roads and utility infrastructure

Future realignment of roadways and utility infrastructure is costly but those costs can be minimized if managed adaptation and retreat policies are established decades before implementation. City and utility agencies and companies can integrate future land use changes into current infrastructure repair and replacement decisions to minimize future costs of infrastructure loss and realignment. Basic cost estimate (based on previous reports) to realign roads and infrastructure that will be at risk by 2100 is outlined in Table 15.

8. Conclusion

The adaptive capacity of Moss Landing to respond to the combined vulnerabilities projected within the 2030 ESA hazard maps is high. The increased risks after 2060, however, of higher energy storm surge, greater fluvial discharge and higher ocean water elevations become a significant threat to the long-term viability of Moss Landing Island and commercial area.

This hazard assessment is intended to provide projections of future risks so the community can begin to adapt and redevelop strategically before emergencies happen. State funding is available to help communities adapt to future risks projected by this study. This hazard evaluation is intended to provide a predictive chronology of future risks to support local planning and future discussions with state regulatory and funding agencies.

POSSIBLE NEXT STEPS

- Conduct a more complete inventory and risk assessment for utility infrastructure (data were not available for this analysis).
- Adopt Capital Improvement Project review guidelines for sea level rise hazard areas.
- Integrate 2030 hazard maps into Moss Landing Community Plan.
- Work with Moss Landing Marine Labs and Monterey Bay Aquarium Research Institute to address lateral access restrictions along the Moss Landing sand spit beach.
- Encourage additional dune restoration activities between Salinas River mouth and the harbor entrance.
- Draft the Moro Cojo tide gate management strategy.
- Work with local stakeholder groups to develop flood accommodation strategies for agriculture within the 2030 hazard area.
- Refine flood and erosion hazard maps to provide additional detail and accuracy;
- Identify assets that are "regional" and the regional risks;
- Consider potential risks to various properties independently for each hazard to better define policy and building guideline alternatives.

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Moss Landing Community
Coastal Climate Change Vulnerability Report

Appendices

JUNE 2017

CENTRAL COAST WETLANDS GROUP

MOSS LANDING MARINE LABS | 8272 MOSS LANDING RD, MOSS LANDING, CA

Appendix A.

Coastal Adaptation Policy Assessment: Monterey Bay

(Center for Ocean Solutions, 2016)

CENTER FOR OCEAN SOLUTIONS

Coastal Adaptation Policy Assessment: Monterey Bay

August 30, 2016

To support decisionmakers in their efforts to manage coastal resources in a changing climate, the Center for Ocean Solutions (Center) engaged with Monterey and Santa Cruz Counties and other partners to model, map and assess the role of natural habitats along the coast of Monterey Bay in providing the ecosystem service of coastal protection. In addition, the Center evaluated existing and potential land use policy strategies that prioritize nature-based climate adaptation strategies. Ecosystem service modeling and assessment was conducted using the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) decision support tool, a suite of tools to map and value the goods and services from nature. Specifically, the Center utilized the InVEST Coastal Vulnerability model for this assessment.

This ecosystem services and adaptation policy assessment focuses on the coastline of Monterey Bay and two specific geographic areas of interest: Capitola in Santa Cruz County and Moss Landing in Monterey County. For each location, we identify the distribution and ecosystem services provided by coastal habitats, map the role of those habitats in reducing exposure to storm impacts, evaluate land use policy adaptation strategies with the potential to maintain or improve nature's role in reducing exposure to these impacts, and highlight policy considerations relevant for each strategy. In addition, we include an introduction to our science-to-policy approach, a compilation of general considerations for pursuing land use policy approaches, as well as a summary of our analysis methodology.

This assessment addresses Task 4B of the Ocean Protection Council's grant entitled: "Collaborative Efforts to Assess SLR Impacts and Evaluate Policy Options for the Monterey Bay Coast." Results from this assessment will inform local planning in both Capitola and Moss Landing, as well as regional or county-wide planning in both Monterey and Santa Cruz Counties. This collaborative, regional project is underway in parallel with other coastal jurisdictions through a statewide investment in updating coastal land use plans in accordance with projections of rising sea levels and more damaging storms.

Coastal Adaptation Policy Assessment: Monterey Bay

Table of Contents

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Coastal Adaptation Policy Assessment: Monterey Bay

EXECUTIVE SUMMARY

As sea levels rise, the impacts of more frequent large storm events driven by the El Niño Southern Oscillation (ENSO) will be greater than those historic events of similar magnitude, exposing coastal areas to the combined effects of elevated tides, increased storm run up and enhanced wave impacts. This increase in the frequency and intensity of storms will likely lead to economic, social and environmental vulnerabilities for coastal communities. California has proactively prioritized coastal adaptation planning that addresses vulnerabilities associated with a changing climate. As a result, the Monterey Bay Region is one of many locations to receive significant funding support to conduct a regional assessment of coastal vulnerability. The results of this coastal adaptation policy assessment will provide information that municipalities can leverage as they engage in adaptation planning for coastal land use.

Successful local, regional and state climate adaptation planning should take into account the role of natural habitats in ensuring a resilient coastline. Coastal habitats can play a protective role in reducing exposure to wind and wave impacts while also providing many additional beneficial ecosystem services to people and nature. Through proactive climate adaptation planning, coastal communities should prioritize nature-based strategies (e.g., dune or wetland restoration, conservation easements, etc.) when and where they are most feasible. If nature-based strategies are not practical in a given location, then coastal planners should consider approaches that seek to maintain the integrity of natural habitats and allow for adaptive coastal planning in the future (e.g., planned retreat, redevelopment limits, etc.).

With combined funding from the State Coastal Conservancy's (SCC) Climate Ready and Ocean Protection Council's (OPC) Local Coastal Program Sea Level Rise grant programs, the Monterey Bay Region is a part of a statewide investment to update coastal land use plans in accordance with projections of rising sea levels and more damaging storms. In parallel with additional select counties, the SCC and OPC provided funding in 2013 for Monterey and Santa Cruz Counties to include impacts from rising sea levels in their ongoing Local Coastal Program updates. The full study area includes the Monterey Bay coastline from Año Nuevo in Santa Cruz County to Municipal Wharf Two in Monterey County. Through discussion with county and city planners as well as with grant organizers from Central Coast Wetlands Group, two community-level study areas were identified—Capitola and Moss Landing—for exposure of coastal assets analyses, the role of natural habitats in reducing coastal exposure and the implications for potential climate adaptation strategies. Detailed analysis and synthesis in these case study locations will be the catalyst for similar investigations throughout Monterey Bay and potentially other sections of the California coast.

<u>Executive Summary: Key Messages</u>

Monterey Bay Coastal Study Area

- The Monterey Bay coastline features diverse coastal habitats including: dense kelp forests; brackish wetland habitats along creeks, lagoons, and sloughs; and expansive beach and dune systems that cover the central and southern sections of the coastline.
- While each coastal habitat plays some protective role, the dune systems in southern Monterey Bay play the highest role in reducing exposure of coastal development to erosion and inundation during storms relative to the entire study area.
- Any climate adaptation strategies under consideration along the Monterey Bay coastline should conform with the strictures of the Coastal Act, consider the recommendations from the Coastal Commission's sea level rise guidance, and respect the cultural significance of the region.
- A primary consideration for proactive coastal adaptation is to incentivize proactive climate adaptation planning that utilizes a blend of approaches across multiple timescales; optimal strategies should not limit adaptation options for future generations.

Capitola

- The small beach and lagoon system at the mouth of Soquel Creek plays a relatively moderate role in reducing exposure to erosion and inundation in comparison with the entire study area.
- The proximity of Capitola's commercial development to the coast limits the city's options for nature-based adaptation strategies.
- Adaptation options for developed sections of Capitola include implementing overlay zones that account for anticipated rising seas. In addition, limiting redevelopment or implementing redevelopment guidelines in these zones can provide a plan for relocation in coming years.

Moss Landing

- Relative to the entire Monterey Bay study area, the large dunes north and south of Moss Landing provide the highest protective role from coastal storm impacts.
- Nature-based climate adaptation options in the Moss Landing case study area include restoration or preservation of dune and wetland habitats. In addition, nourishing beachfront locations with additional sediment can be an option if appropriate environmental concerns are addressed.
- Built structures—including some coastal dependent structures—limit adaptation options for parts of Moss Landing. Critical infrastructure such as the Moss Landing power plant, harbor infrastructure, and Highway 1 all present challenges to implementing many otherwise viable strategies.

Our Climate and Ecosystem Services Science-to-Policy Approach

Coastal decisionmakers are actively determining how coastal communities will adapt to rising sea levels and more damaging storms. Favorable adaptation approaches consider the role of natural habitats and prioritize resilient strategies that do not limit future planning options.[1] Since 2010, the Center for Ocean Solutions has worked with coastal planners and managers to incorporate the role of natural habitats in climate adaptation planning.[2] Below, we outline our scalable, transferable approach to bridging a spatial assessment of natural protective services with coastal land use policy decisions in an era of changing climate.[3]

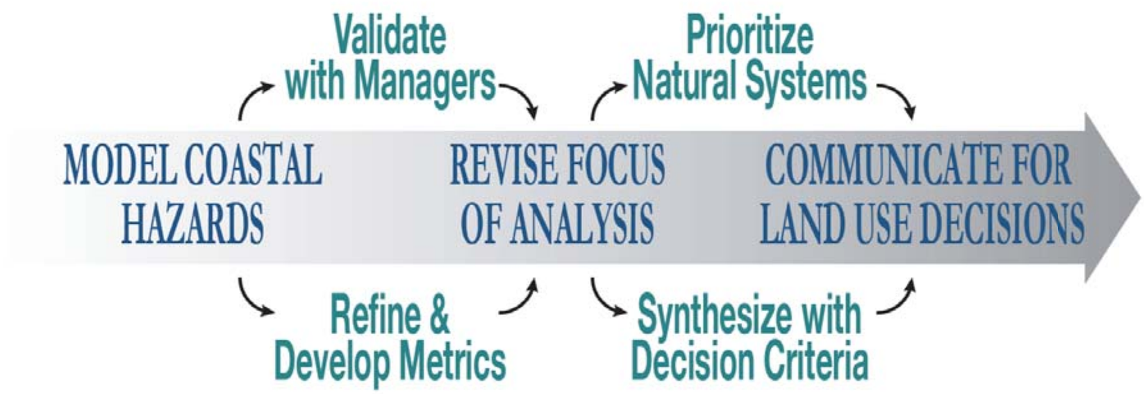

Fig. 1: Our transferable, scalable ecosystem services to coastal adaptation policy approach.

Coastal Ecosystem Services

Ecosystem services are the benefits that natural habitats provide to people (e.g., water purification, aesthetic attachment, carbon sequestration and coastal protection). Thriving, healthy ecosystems provide the greatest provision of services and are most resilient in the face of dynamic environmental conditions. In the coastal context, ecosystems play an important role in protecting shorelines against wave action by dissipating wave energy, or, in the case of sand dunes, physically impeding wave run-up. Climate change impacts, such as rising sea levels and increased storm intensity, are altering patterns of wave action along the coast and exposing new locations to physical forces. As waves travel from the open sea to coastal regions with shallower waters, they interact with the natural and geologic features of the seabed. Increased intensity and frequency of storms and rising seas, further emphasizes the important role of coastal habitats in reducing shoreline erosion and of increasing resilience in coastal areas.

[1] Jon Barnett & Saffron O'Neill, *Maladaptation* 20 GLOBAL ENVTL. CHANGE 211 (2010).
[2] Suzanne Langridge et al., *Key lessons for incorporating natural infrastructure into regional climate adaptation planning* 95 OCEAN & COASTAL MANAGEMENT 189 (2014); Sarah Reiter et al., *Climate Adaptation Planning in the Monterey Bay Region: An Iterative Spatial Framework for Engagement at the Local Level* 6 NATURAL RESOURCES 375 (2015); Lisa Wedding et al., *Modeling and Mapping Coastal Ecosystem Services to Support Climate Adaptation Planning*, *in* OCEAN SOLUTIONS EARTH SOLUTIONS 389 (Dawn J. Wright ed., 2016).
[3] *See* Figure 1. For further information on this approach, see also the "Analysis, Methodology and Assumptions" section *infra*.

Diverse habitats along California's coastline (e.g., sea grasses, kelp forests, salt marshes, dunes) play a role in reducing exposure to storm impacts while also providing a variety of additional services. As coastal development and rising sea levels degrade or damage these habitats, coastlines, communities and infrastructure become increasingly vulnerable to storms. An important challenge for decisionmakers is determining the best climate adaptation strategies that protect people and property while also protecting the ability of coastal habitats to provide a protective service into the future. To address this challenge, coastal communities need to identify where natural habitats provide the greatest protective benefits so that they may prioritize adaptation planning efforts that protect or restore their critical natural habitats.

Spatial Modeling and Mapping of the Protective Services

Modeling and mapping the ecosystem service of coastal protection can support the spatial prioritization of science-based climate adaptation strategies. For this assessment, we used InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) in combination with ArcGIS to identify areas where natural coastal habitats provide greater relative protection from storms and shoreline erosion.[4] The spatial models account for service supply (e.g., natural habitats as buffers for storm waves), the location and activities of people who benefit from services and infrastructure potentially affected by coastal storms. The InVEST Coastal Vulnerability model produces a qualitative estimate of coastal impact exposure to erosion and inundation during storms. By coupling exposure results with population information, it can identify the areas along a given coastline where humans are most vulnerable to storm waves and surge. The model does not value any environmental service directly, but ranks sites as having a relatively low, moderate or high risk of erosion and inundation through an exposure index.

The Coastal Exposure index is calculated by combining the ranks of the seven biophysical variables at each shoreline segment: geomorphology, natural habitats (biotic and abiotic), net sea level change, wind and wave exposure, surge potential and relief (bathymetry and topography). Model inputs serve as proxies for various complex shoreline processes that influence exposure to erosion and inundation. The resulting coastal exposure ranks range from very low exposure (rank=1) to very high exposure (rank=5), based on a mixture of user- and model-defined criteria. The model output helps to highlight the relative role of natural habitats at reducing exposure—also through a 1–5 ranking. This relative role output can be used to evaluate, how certain management actions can increase or reduce exposure of human populations to the coastal hazards of erosion and inundation. For this assessment, the model outputs were mapped on the shoreline of the Monterey Bay study area in order to interpret the relative role of natural habitats in reducing nearshore wave energy levels and coastal erosion—thus highlighting the protective services offered by natural habitats to coastal populations.

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[4] InVEST is a free and open-source suite of software models created by the Natural Capital Project at the Stanford Woods Institute for the Environment to map and value the goods and services from natural capital. *See* INTEGRATED VALUATION OF ECOSYSTEM SERVICES AND TRADEOFFS, http://www.naturalcapitalproject.org/models/coastal_vulnerability.html (last visited Aug. 30, 2016).

Coastal Vulnerability Model Considerations

While this vulnerability modeling approach includes average wave and storm conditions, the InVEST Coastal Vulnerability model does not account for coastal processes that are unique to a region, nor does it predict changes in fluvial flooding or shoreline position or configuration. The model incorporates a scenario-based approach to evaluate the role that coastal habitats play in reducing exposure to coastal impacts. We use the Coastal Vulnerability index here to better understand the relative contributions of different input variables to coastal exposure and highlight the protective services offered by natural habitats to coastal populations. Results provide a qualitative representation of erosion and inundation risks, rather than quantifying shoreline retreat or inundation limits. The compiled role of habitat map products depicts results from a "presence/absence" analysis that calculates the difference between erosion indices with and without habitats in place. In effect, this approach indicates the change in coastal exposure if natural habitats are lost or degraded.

Connecting Spatial Modeling to Planning

Understanding the role that nearshore habitats play in the protection of coastal communities is increasingly important in the face of a changing climate and rising seas. To develop this analysis, we integrated feedback from coastal planners to better understand their information needs on coastal vulnerability and potential adaptation options. The map products created from the InVEST Coastal Vulnerability model support the spatial evaluation of nature-based adaptation planning alternatives with rising sea levels, and highlight how protective services might change in the future. Connecting these model results with existing land use planning and zoning information and current policies provides a pathway for identifying locations in which nature-based strategies can be prioritized as more effective and feasible than competing traditional strategies.

Monterey Bay Coastal Study Area

Monterey Bay Coastal Management Context

The study area from Año Nuevo in Santa Cruz County to Wharf Two in Monterey County features a diverse range of land uses and densities. This range includes the City of Santa Cruz's highly developed coastline, the sparsely populated coastal properties of southern Santa Cruz County, and undeveloped beaches in Santa Cruz and Monterey Counties.[5] Farmlands dominate much of the inland areas, especially around Watsonville, Castroville, and Salinas. The main feature of the coastline is the Monterey Bay itself, which includes a submarine canyon leading seaward from Elkhorn Slough and the coast of Moss Landing. The Moss Landing power plant is the largest structure on the Bay, and the coastline features numerous important points of interest, roads, critical infrastructure, and research and educational facilities.

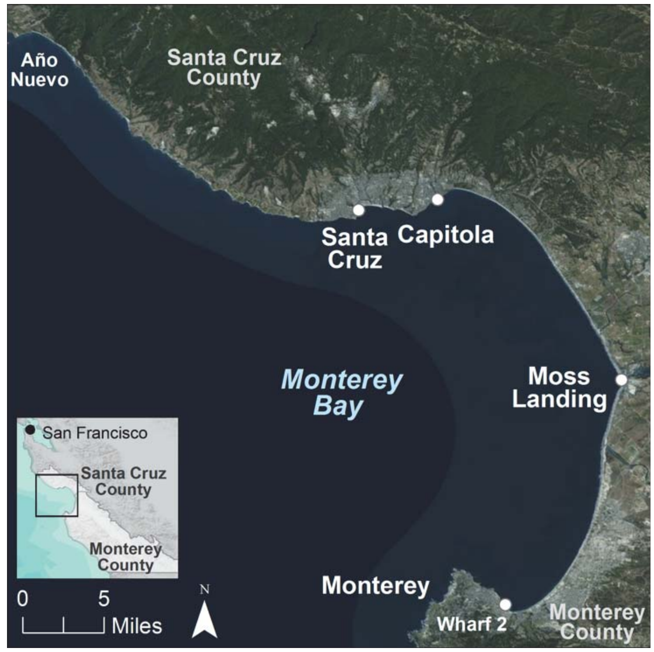

Fig. 2: Satellite image of Monterey Bay.

Several governmental agencies oversee the Monterey Bay coastline. For instance, the California Department of Parks and Recreation manages the state parks and reserves. The California Department of Transportation (CalTrans) oversees the coastal roadways, particularly the Pacific Coast Highway (Highway 1). The California Energy Commission regulates the Moss Landing power plant. The U.S. Fish and Wildlife Service governs the Salinas River National Wildlife Refuge. The National Oceanic and Atmospheric Administration (NOAA) administers the Elkhorn Slough National Estuarine Research Reserve (ESNERR) in partnership with the California Department of Fish and Wildlife. ESNERR and the non-profit Elkhorn Slough Foundation protect 5,500 acres of land, comprising property owned and managed by the reserve and property owned or managed by the foundation in the surrounding hillsides.[6] NOAA also administers the Monterey Bay National Marine Sanctuary and has jurisdiction over the marine mammals in the area. The most active land management agencies in the coastal zone include: the California Coastal Commission, which oversees land use and public access; the State Coastal Conservancy, which strives to protect or improve natural coastal ecosystems; and the State Lands Commission, which manages California's public trust lands.[7]

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[5] The full project study area includes the Monterey Bay coast from Año Nuevo in Santa Cruz County to Municipal Wharf Two in the City of Monterey. Note that this study area does not include sections of Santa Cruz County north of Año Nuevo or sections of Monterey County west and south of Wharf 2. *See* Figure 2.

[6] ELKHORNSLOUGH.ORG, http://www.elkhornslough.org/conservation/what.htm (last visited Aug. 29, 2016).

[7] Public trust lands are held and managed by the state for the benefit of the public. In the coastal zone, public trust lands include all ungranted tide and submerged lands. The Coastal Commission also retains some oversight over the use of granted tide and submerged lands.

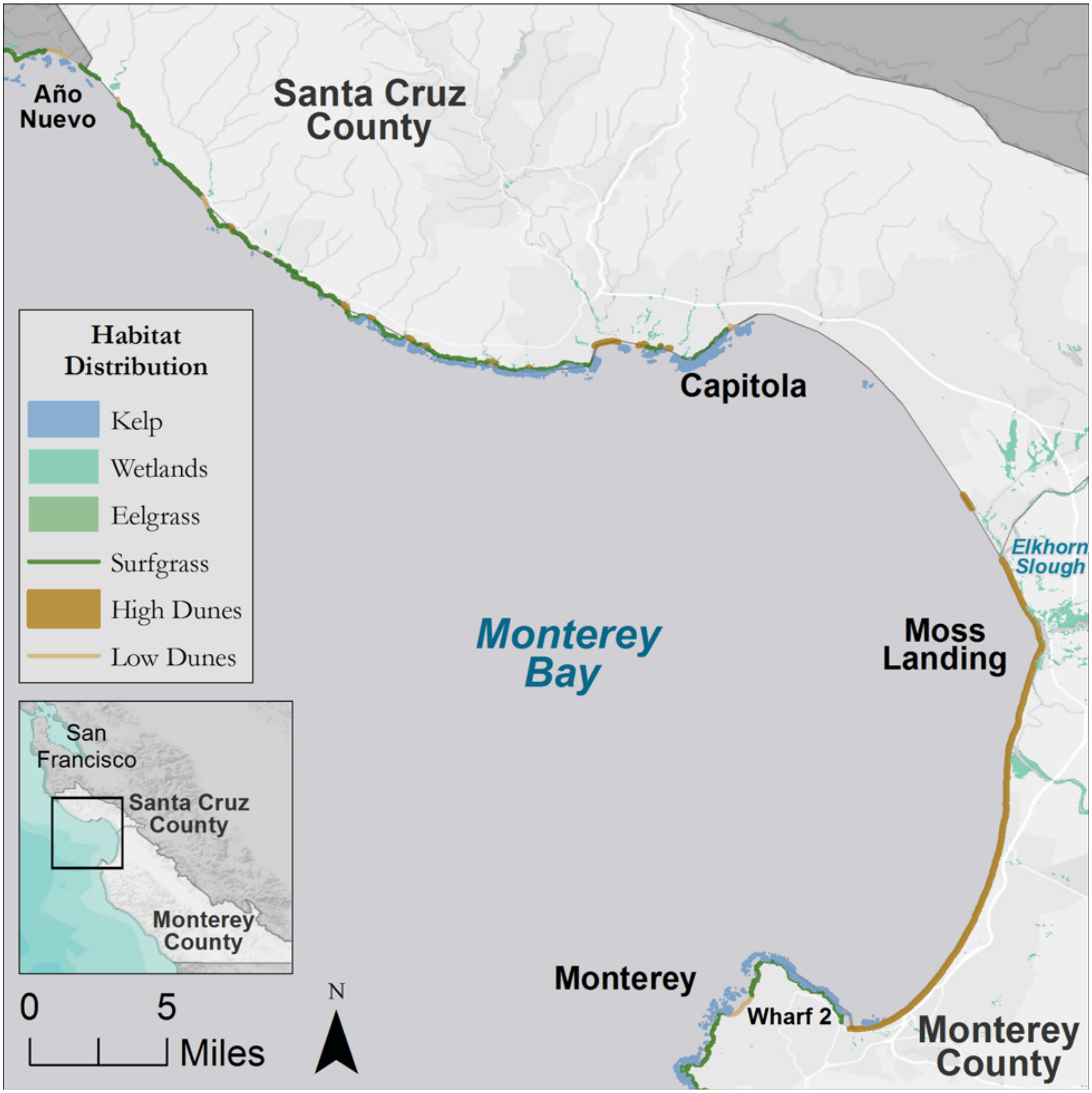

Fig. 3: Coastal habitats in Monterey Bay and surrounding area.

The Pacific coast of Santa Cruz and Monterey Counties has extensive natural habitats including some of the most imperiled habitats in the United States. Freshwater wetlands, coastal prairie and maritime chaparral, as well as kelp forests, estuarine wetlands, small and large beaches, and dunes are all present in the region.[8] The northern section of the study area (Año Nuevo to Capitola) includes a mostly rocky coastline fronted by seaweeds and surfgrass, backed by open agricultural lands. Occasional pocket beaches, typically fed by creeks, interrupt the bluffs and provide coastal access. Near the river mouths of the city of Santa Cruz, there is a greater concentration of small pocket beaches and wetland habitats than elsewhere in the area. The central section of the study

[8] *See* Figure 3.

area (Capitola to Moss Landing), is predominantly characterized by beaches and low dune systems backed by cliffs that decrease in size from north to south. The southern section of the study area (Moss Landing to Monterey) is dominated by large dune systems at the southern extent of the Santa Cruz littoral cell—the cycle of sediment sources and sinks from Pillar Point to the Monterey Canyon.[9] These habitats are all locally important and provides significant ecosystem services and benefits to certain communities.

Monterey Bay Protective Role of Habitats

Coastal habitats provide the ecosystem service of coastal protection for people, property and infrastructure by providing a natural buffer to mitigate erosion and inundation from ocean waves and storms. Our analysis focused on the direct effects of sea level rise on the risk of coastal communities to erosion and flooding. Our model results suggest that with rising sea levels the ability of dune systems to mitigate coastal exposure and keep this section of coastline in the low-moderate exposure range could be compromised.[10] Rising seas will likely impact the protective role of many beaches and dune habitat backed by coastal armoring that could result in the loss of existing beach area and the associated recreation and tourism income to coastal communities.[11] Overall, the loss of coastal dunes, wetlands, kelp forests and seagrass habitats would increase the exposure to erosion and flooding along the Monterey Bay study area. The extensive high dune systems throughout the southern section of Monterey Bay play a relatively high protective role compared to other natural habitats along the coastline. Storm surge is an important model factor from Marina to Monterey which alludes to the high role of coastal habitats in this area for protecting people and property along the coast. The coastal dune habitat in the Monterey Bay region suffers from high rates of erosion.[12] As a result, shoreline armoring has been used extensively along developed areas to address erosion and protect infrastructure and other areas of coastal development from waves, erosion and inundation. With increasing human pressure on these coastal ecosystems, there is a need to prioritize adaptation planning efforts in these important dune systems and other habitats that play significant roles in coastal protection.

Coastal wetlands along Monterey Bay stabilize shorelines and protect coastal communities by attenuating waves. Wetland habitat in the study area provides a relatively moderate role in mitigating erosion and inundation during storms. As sea levels rise, wetlands need to migrate to maintain their protective role. A recent study in Santa Cruz found that 17% of wetland habitat will be unable to migrate with sea level rise due to existing development.[13] The model does not predict migration or loss of habitat under the different sea level rise scenarios. Further research is needed to understand the extent to which habitats will be able to adapt to climate change effects.[14]

[9] U.S. ARMY CORPS OF ENGINEERS, COASTAL REGIONAL SEDIMENT MANAGEMENT PLAN FOR THE SANTA CRUZ LITTORAL CELL, PILLAR POINT TO MOSS LANDING (2015).
[10] *See* Figure 4.
[11] Philip G. King et al., THE ECONOMIC COSTS OF SEA-LEVEL RISE TO CALIFORNIA BEACH COMMUNITIES (2011).
[12] Gary Griggs & Rogers Johnson, *Coastline erosion: Santa Cruz County, California* 32 CALIFORNIA GEOLOGY 67 (1979); Edward Thornton et al., *Sand mining impacts on long-term dune erosion in southern Monterey Bay* 229 MARINE GEOLOGY 45 (2006).
[13] MATTHEW HEBERGER ET AL., THE IMPACTS OF SEA-LEVEL RISE ON THE CALIFORNIA COAST (2009).
[14] Langridge, *supra* note 2.

The southern coastline of Monterey Bay is exposed to high wave energy, which was a substantial driver of the high coastal exposure in this area. Surfgrass provides some wave attenuation for the adjacent shoreline but compared to other habitats in the study area, it plays a relatively low role in reducing overall exposure. Although kelp forest habitats along the broader Monterey Bay coastline also play a relatively low role in reducing exposure to coastal hazards compared to the coastal dune habitats, these habitats offer important co-benefits to California's people and the economy such as fisheries habitat and recreation.

Monterey Bay Ecosystem Services of Coastal Habitats

The Monterey Bay is nationally regarded as a culturally important marine habitat. This section of the coast includes six state marine protected areas as well as a national marine sanctuary.[15] Monterey Bay also supports a diverse ocean and coastal-based economy including agriculture, tourism, industry, aquaculture, fishing as well as a number of marine research and education institutions. Many tourists flock to the area for offshore whale watching, coastal birding, kayaking, surfing, boating, fishing, and beach-going. The diverse habitats noted below play an important role in preserving the open natural system of this region.

Creeks, Rivers, and Lagoons

Along the Northern coast of Monterey Bay there are numerous creeks and rivers reaching coastal lagoons and beaches along the Pacific shoreline. Several waterways also weave through the urbanized residential areas in Santa Cruz or Capitola, along with more rural neighborhoods such as in Aptos. These coastal waterways provide habitat for commercially important fish species (e.g., salmon and steelhead) during juvenile stages of their lifecycle. Many non-commercial fish and birds are also endemic to these creeks, while amphibians and reptiles use the damp banks for shelter and a source for food.[16] These riparian corridors and their lagoons provide aesthetic value and streamside recreation opportunities in the form of parks and trails, particularly in more urbanized neighborhoods. They also perform water filtration services, and nutrient cycling. When this habitat remains intact, it can aid in flood control and water storage during the wet season and major storm events.[17]

[15] The Marine Protected Areas include: Greyhound Rock and Elkhorn Slough State Marine Conservation Areas as well as Año Nuevo, Natural Bridges, Elkhorn Slough, and Moro Cojo State Marine Reserves.
[16] Mary E. Power et al., *Rivers*, *in* ECOSYSTEMS OF CALIFORNIA 713 (Harold Mooney & Erika Zavaleta eds., 2016).
[17] Walter G. Duffy et al., *Wetlands*, *in* ECOSYSTEMS OF CALIFORNIA 669 (Harold Mooney & Erika Zavaleta eds., 2016).

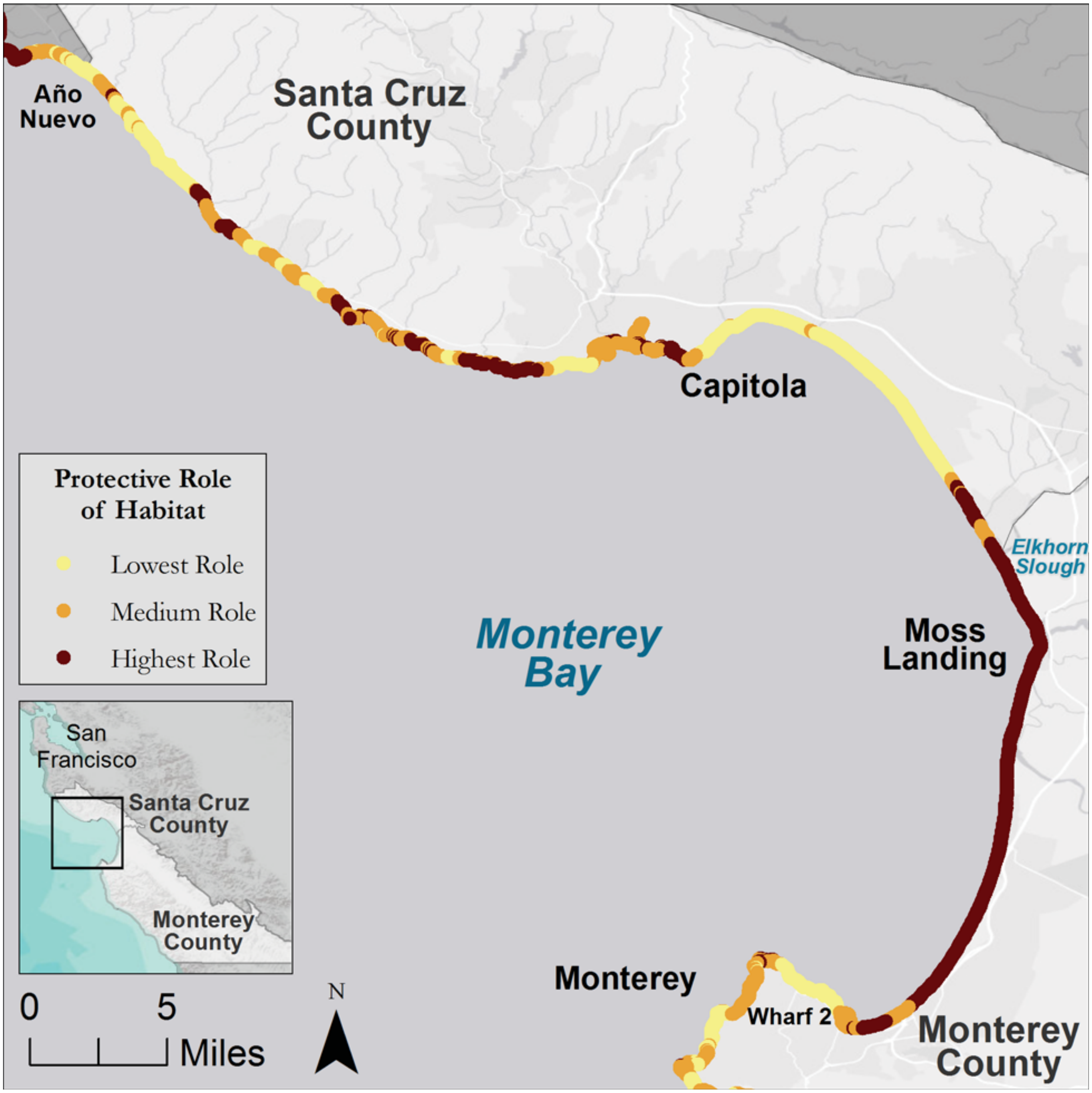

Fig. 4: Relative role of coastal habitats around Monterey Bay in reducing exposure to erosion and inundation.

Kelp Forests of Monterey Bay's Northern Coast

On the Northern end of the bay, near Año Nuevo, dense kelp forests grow from the sandstone and claystone reefs offshore. Kelp forests provide juvenile fish habitat and shelter them from predation. Kelp is also harvested at small scales to provide food for abalone aquaculture, particularly for abalone farms along the wharfs of Monterey.[18] Since no recreational or commercial fishing of any abalone species is allowed south of San Francisco, local aquaculture operations are the only source

[18] Mark H. Carr & Daniel C. Reed, *Shallow Rocky Reefs and Kelp Forests*, *in* ECOSYSTEMS OF CALIFORNIA 311 (Harold Mooney & Erika Zavaleta eds., 2016).

of Monterey Bay abalone for human consumption.[19] Forests of giant kelp (*Macrocystis pyrifera*) and bull kelp *(Nereocystis luetkeana*), nourished by cold, nutrient-rich waters, are highly productive and support a food web of hundreds of fish and invertebrate species along with a diverse assemblage of birds and marine mammals.[20] In addition, litter from broken kelp fronds washes up on local beaches as wrack and detritus, sustaining a separate food web of terrestrial insects and shorebirds.[21] Kelp require high light levels and cool water temperatures to grow. As such they are sensitive to excess sedimentation and nutrient overloads that stimulate growth of light-blocking organisms. Strong wave action from storms can rip out entire kelp patches and significantly damage the remaining fronds. Accordingly, shifts in ocean thermal regimes or winter storm patterns such as El Niño can pose threats to sustaining kelp habitats.[22]

Wetlands of Elkhorn Slough

At the heart of Monterey Bay is Elkhorn Slough, an estuarine system known for its biological significance. Its channels, mudflats, eelgrass beds, salt marshes, and hard substrates provide habitat for more than 100 fish, 265 bird, and 500 marine invertebrate species, and more than two dozen rare, threatened, or endangered species.[23] Elkhorn Slough also provides safe habitat for several species of marine mammals. Sheltered from larger marine predators, harbor seals and Southern sea otters use the Slough as a safe feeding and pupping ground. Because of its rich diversity of birds and mammals, Elkhorn Slough's sheltered waters are a popular location for kayaking, paddle boarding, and wildlife viewing. These wetlands contribute to flood control, water filtration, and nitrogen runoff control services.[24] Wetlands provide additional benefits as sinks for carbon through their vegetation growth and accumulation of slowly decomposing sediment.[25]

Coastal Dune and Beach Systems

Extensive coastal dune systems along the southern coast of Monterey Bay support important plant communities between mean high tide and the furthest reach of storm waves.[26] The Monterey Bay beaches and dunes are also a favorite for locals and tourists alike due to its pristine coastline and sandy shores along many coastal access sites. The beach and dune habitats in this region also

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[19] CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE, STATUS OF THE FISHERIES REPORT (2011).

[20] Yuri Springer et al., *Toward ecosystem-based management of marine macroalgae—the bull kelp, Nereocystis luetkeana* 48 OCEANOGR. MAR. BIOL. ANNUAL REVIEW 1 (2010); *see also* Carr & Reed, *supra* note 18.

[21] Jenny Dugan et al., *The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California* 58 ESTUARINE COASTAL AND SHELF SCIENCE 25 (2003).

[22] Yuri Springer et al., *Toward ecosystem-based management of marine macroalgae - the bull kelp, Nereocystis luetkeana* 48 OCEANOGRAPHY AND MARINE BIOLOGY: AN ANNUAL REVIEW 1 (2010); Paul Dayton & Mia Tegner, *Catastrophic Storms, El Niño, and Patch Stability in a Southern California Kelp Community* 224 SCIENCE 283 (1984).

[23] CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH 4 (Jane Caffrey et al. eds., 2002) (Elkhorn Slough's habitats include "the slough's channels, mudflats, eelgrass beds, salt marsh, and hard substrate; the adjacent harbor, coastal dunes, and open beaches; and the grasslands, oak, woodlands, chaparral, and other upland areas.").; Jessica Lyons, *Scientists and Activists Aim to Save Elkhorn Slough from Erosion and Development Before it is too Late*, MONTEREY CNTY. WEEKLY, Dec. 13, 2007, *available at* http://www.montereycountyweekly.com/news/cover/article_11c69d2e-dfd5-502d-92ca-bada34be8709.html.

[24] James E. Cloern et al., *Estuaries: Life on the Edge, in* ECOSYSTEMS OF CALIFORNIA 359 (Harold Mooney & Erika Zavaleta eds., 2016).

[25] John Callaway et al., *Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands* 35 ESTUARIES AND COASTS 1163 (2012).

[26] Iris Hendriks et al., *Photosynthetic activity buffers ocean acidification in seagrass meadows* 11 BIOGEOSCIENCES 333 (2014).

provide numerous benefits to people and nature, such as critical shoreline bird habitat, mammal haul out locations, as well as coastal recreation and shoreline fishing spots.

General Policy Considerations
There are several general policy considerations that apply to the entire study area, regardless of the adaptation strategy implemented.[27] Most importantly, any climate adaptation strategies should conform to the various strictures of the Coastal Act, and take into account the Coastal Commission's sea level rise recommendations. Additionally, adaptation solutions should be place-based, designed with each specific location's characteristics and limitations in mind. Adaptation strategies should also incentivize proactive planning and limit subsidizing building in hazardous locations. Finally, the cultural significance of the study area should be considered. These considerations are investigated below.

The Coastal Act sets out various legal requirements with which all coastal adaptation policies must be consistent.[28] Likewise, the Commission's Sea Level Rise Guidance (Guidance) contains several persuasive and compelling recommendations. The Guidance recommends pursuing a suite of actions designed to protect in the short term, accommodate in the midterm, and promote retreat in the long term, instead of focusing on any one strategy type or time scales.[29] This hybrid approach permits flexibility and allows communities to tailor adaptation strategies to their unique circumstances. For instance, it would allow the use of protection, accommodation, and retreat strategies simultaneously—as needed and as appropriate—and would also allow these strategies to change over time.[30] Under such an approach, protection of existing structures is allowed but may be limited by certain factors, such as the economic life of a structure.

While a variety of coastal adaptation strategies for adjusting coastal land uses in response to climate impacts are possible in any given area, the appropriate adaptation measures for specific locations will depend on factors such as those locations' topographies and existing infrastructure. Accordingly, each location's unique characteristics should inform the adaptation strategies employed there. For example, the strategies suitable for the study area's open and undeveloped coastlines are likely unsuitable for the city of Santa Cruz and other highly developed areas. Furthermore, specific strategies should take into account predicted rates of local sea level rise and an area's vulnerability to storm events. Finally, existing regulations for each targeted location—such as local coastal programs, rules specific to the Monterey Bay National Marine Sanctuary[31] and any other applicable federal, state or local laws[32]—should be noted and followed.

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[27] These considerations are in addition to the overarching policy consideration of this assessment: that nature-based solutions could be prioritized when possible to ensure maximum co-benefits and beneficial services associated with these strategies.
[28] *See, e.g.*, CAL. PUB. RES. CODE §30235.
[29] CALIFORNIA COASTAL COMMISSION, SEA LEVEL RISE ADOPTED POLICY GUIDANCE 125 (2015) *available at* http://www.coastal.ca.gov/climate/slrguidance.html.
[30] *Id.* at 122-23 ("In many cases, a hybrid approach that uses strategies from multiple categories will be necessary, and the suite of strategies chosen may need to change over time.").
[31] *See, e.g.*, 15 C.F.R. § 922.132 (listing prohibited or otherwise regulated activities in the MBNMS).
[32] For instance, the National Historic Preservation Act of 1966 would govern efforts to move or alter historic buildings on the National Register of Historic Places. 16 U.S.C. §§ 470 *et seq.*

Keeping these limitations in mind, communities should pursue strategies that internalize the risks associated with building and buying properties in hazardous locations and incentivize proactive planned retreat and relocation where appropriate. Proactive planning is especially important in areas with a large number of repetitive loss properties, such as Aptos.[33] Superstorm Sandy and other disasters have proven that making decisions early is less expensive, and potentially less devastating, than waiting until the effects of a disaster take hold.[34] One way governments could internalize the risks associated with building in hazardous locations would be to stop spending public funds to rebuild private structures on sites damaged by rising seas and storms. Another option to internalize these risks would be to amend existing flood insurance policies.[35]

The cultural significance of California's beaches and the Monterey area can also be considered. California's beaches are important to Californians and play a large part in the State's identity. Furthermore, Monterey, and its surrounding areas, are culturally important for many reasons. Coastal adaptation planning can take the area's rich heritage into account when considering which coastal adaptation strategies to pursue. Particularly, adaptation decisions should consider the potential social impacts of decisions affecting culturally and socially significant areas. Moreover, culturally important points of interest in the area should be preserved if possible. Accordingly, decisionmakers can consider the social impacts of any proposed adaptation actions when prioritizing coastal adaptation strategies.

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[33] Particularly State Park Drive and Beach Drive in Aptos, CA. COUNTY OF SANTA CRUZ LOCAL HAZARD MITIGATION PLAN 2015-2020 64 (2015) *available at* http://www.sccoplanning.com/Portals/2/County/Planning/policy/2015%20LHMP%20Public%20Review%20Draft.pdf.

[34] *See, e.g.*, Anne R. Siders, *Anatomy of a Buyout—New York Post-Superstorm Sandy*, Vermont Law School 16th Annual Conference on Litigating Takings Challenges to Land Use and Environmental Regulations (Nov. 22, 2013) (explaining lessons learned in acquisition and buyout programs post-Sandy in New York).

[35] Such a change would need to come at the federal level through amendment to the National Flood Insurance Program. 42 U.S.C. § 4001.

Community-Level Study Areas

Capitola: Coastal Setting

Capitola was one of the earliest populated beaches on the west coast and hosts a highly developed coastline. Similar to the neighboring city of Santa Cruz, Capitola faces flooding, cliff erosion and episodic bluff failure during King Tides—highest annual tides—and ENSO storm events. Soquel Creek bisects Capitola, and its beach, and plays a large role in riverine inundation in the area. Riprap lines the beach and protects both the beach and development beyond it, such as a modest commercial area that is the economic center of the community.

Fig. 5: Satellite image of Capitola.

Capitola's unique characteristics inform the adaptation policies and strategies that might be prioritized in the area.[36] The coastal city of Capitola is dominated by steep cliffs, pocket beaches and low dune systems. Surfgrass beds line the shore and kelp forests populate nearshore reefs from the mouth of Soquel Creek westward toward the city of Santa Cruz. There are a number of low coastal terraces and cliffs that allow coastal access to these scattered beaches. Downtown Capitola and Capitola Beach are saddled between two steep coastal cliffs forming an economically important beachfront tourist destination and coastal recreation site for the community. Soquel Creek runs through downtown Capitola, housing a string of wetlands before flowing to the ocean through an ephemeral lagoon system.

Capitola: Protective Role of Habitats

The low dune and beach habitat in Capitola plays a relatively moderate role in reducing the exposure of Capitola Village and the mouth of Soquel Creek to erosion and inundation during storms compared to the lower protection provided by rest of the adjacent coastline.[37] Beach sands in front of the creek mouth buffer wave run-up and the reach of salt water upstream during storm surge. The main drivers of coastal exposure in the Capitola area are the low elevation and erodible geomorphology surrounding Soquel Creek. The presence of wetlands reduces wave heights along the overall Monterey Bay coastline as coastal wetland and creek vegetation serve as a shoreline buffer. However, model results suggest that Soquel Creek does not serve a strong role in protecting the Capitola shoreline in all locations or scenarios due to the low-lying elevation and coastal flooding during storm events. This phenomenon is not unique to Soquel Creek as large scale regional erosion and river outflow can often overwhelm the ability of vegetation to attenuate waves.[38] The Capitola area is less exposed to wind and waves compared to the broader Monterey Bay study region, yet the relatively greater distance from the continental shelf drives an increase in storm surge potential. Kelp forest habitats along the broader Capitola coastline play a relatively low protective role, based on the model ranking methodology, in reducing exposure compared to the coastal dune and wetland habitats in this area.

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36 *See* Figure 5.
37 *See* Figure 6.
38 Keryn Gedan et al., *The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm* 106 CLIMATIC CHANGE 7 (2011).

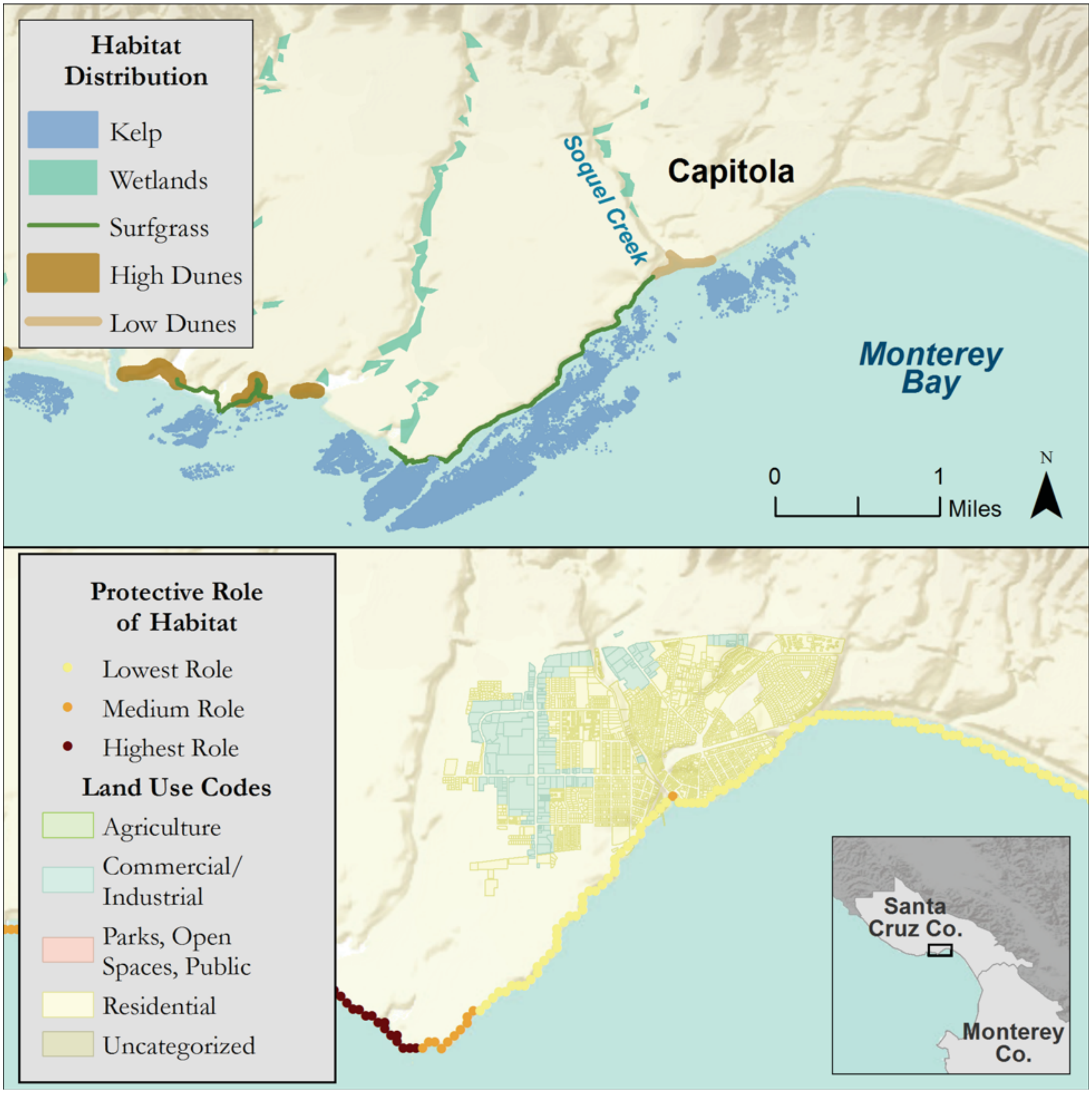

Fig. 6: Coastal habitats around Capitola, CA (Top). The relative role of coastal habitats along the shoreline of Capitola in reducing exposure to erosion and inundation with relevant land use zoning information (Bottom). Land use categories from the General Plan Land Use Codes were aggregated into four broad land use codes (see Bottom legend). Nearly all areas belonged distinctly to one category of land use. Only one land classification, Visitor Serving/L-M Density Residential, had uses from multiple categories, and it was categorized as Residential for this map.

Capitola: Ecosystem Services of Coastal Habitats

Wetlands in Riverine System

As Soquel Creek approaches the Pacific Ocean, the change in slope provides opportune locations for wetland habitats that slow the pace of the river and filter nutrients and pollutants, which leads to an improvement in water quality.[39] Closer to the coast, the river may transition into a lagoon

[39] Duffy et al., *supra* note 17.

system depending on the extent of the beach and low dune system at the mouth. Fish, small invertebrates and birds inhabit the lagoon as a feeding and breeding ground.[40] During strong rains, the lagoon typically breaches to create a direct opening to the ocean.[41] The distinction between this tidal versus lagoon interface plays a significant role in managing flood risks for the city of Capitola, particularly due to the many homes that line the creek and lagoon. While lagoon status influences the volume of tidal water that enters the creek system, intact wetlands can buffer surrounding areas against inundation. For instance, water is absorbed into soils instead of collecting on impermeable surfaces.[42]

Coastal Dune and Beach Systems
The beach and low dune habitat along the mouth of Soquel Creek provides the coastal community with recreation opportunities (e.g., surfing, fishing, kayaking, swimming, beach access). The Capitola Village and beach areas near the mouth of the creek draw over twenty percent of Santa Cruz County's tourism visitors annually.[43] The lagoon system at the mouth of Soquel Creek is actively managed by articifical breaching to release water as part of flood control and water quality maintainence. When open to the ocean, lagoons effectively function as small estuaries. Breaching alters the amount of tidal exchange, temperatures, salinity profiles and water flow for the lower portion of the creek. Depending on time of year and conditions surrounding the breaching event, the shift from closed to open system may influence patterns of species movement and habitat use.[44] Controlled breaching events are typically closely overseen by City Watershed Management monitoring teams, with crews on hand to keep threatened and endangered fish in their respective habitats with nets or transport upstream if needed.[45]

Kelp Forests and Surfgrass
Surfgrass and kelp forest habitats near the Capitola shoreline serve an important natural service by providing food and habitat for a suite of marine species that are also important to recreational fishing for residents and visitors. Kelp forests of the Monterey Bay support rockfish, urchins, crabs and many other commercially valuable species, while surfgrass acts as a nursery for juveniles of these adult kelp forest species.[46] Detritus from kelp forests washes out into open water and submarine canyons, providing subsidies of nutrients and food material to the Monterey Bay's deeper habitats.[47]

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[40] Cloern et al., *supra* note 24.
[41] *Id.*
[42] Walter Duffy and Sharon Kahara, *Wetland ecosystem services in California's Central Valley and implications for the Wetland Reserve Program* 21 ECOLOGICAL APPLICATIONS S18 (2011).
[43] LAUREN SCHLAU CONSULTING, SANTA CRUZ COUNTY VISITOR PROFILE (2010).
[44] Cloern et al., *supra* note 24.
[45] Jessica York, *Beach lagoon breached to alleviate flooding*, SANTA CRUZ SENTINEL, August 17, 2015, http://www.santacruzsentinel.com/article/NE/20150817/NEWS/150819676.
[46] Kevin Hovel, *Habitat fragmentation in marine landscapes: relative effects of habitat cover and configuration on juvenile crab survival in California and North Carolina seagrass beds* 110 BIOLOGICAL CONSERVATION 401 (2003); Carey J. Galst & Todd W. Anderson, *Fish-habitat associations and the role of disturbance in surfgrass beds* 365 MARINE ECOLOGY PROGRESS SERIES 177 (2008); *see also* Carr & Reed, *supra* note 18.
[47] Christopher Harrold et al., *Organic enrichment of submarine-canyon and continental-shelf macroalgal drift imported from nearshore kelp forests benthic communities by macroalgal drift imported from nearshore kelp forests* 43 LIMNOLOGY & OCEANOGRAPHY 669 (1998).

Both kelp forests and surfgrass beds also have potential to sequester some carbon dioxide from the atmosphere and surrounding water by incorporating carbon into their tissues. On a short-term scale, photosynthesis temporarily removes carbon dioxide from the water during the day, potentially reducing the impacts of ocean acidification.[48] Over time, marine sediments slowly bury and trap the plant matter—and therefore the carbon—for longer time scales.[49] As carbon sequestration markets develop, this ecosystem function could be of economic interest to the Capitola area from both a hazard and emission mitigation perspective.

Capitola: Adaptation Strategies & Considerations

Coastal Adaptation Options

Capitola's highly developed coastline limits the available coastal adaptation options. Due to high-density development and the prevalence of cliffs and bluffs, limited opportunities exist to apply nature-based strategies, with the exception of Capitola's beach—a possible candidate for beach nourishment. Beach nourishment could reinforce the beach and surrounding areas, slowing coastal erosion due to rising seas. This strategy would also buffer the upland structures—at least in the short term—from rising seas and storm events.

Other adaptation options would also be feasible in Capitola. A particularly useful and flexible option would be to develop sea level rise overlay zones for Capitola's vulnerable areas.[50] An overlay zone is a tool that groups certain properties together because of a feature they share, or because of some regulatory aim that a local government wishes to accomplish. An overlay zone would allow additional zoning regulations or building code restrictions to be established in the future for the properties in that zone, as deemed necessary. Establishing a sea level rise overlay zone would provide immediate notice to owners of homes and businesses that they are in an area that is vulnerable to rising sea levels.[51] This zone could be coterminous with, or go beyond, existing floodplain zones in the area.[52]

Overlay zones can also designate certain areas as protection, accommodation, or retreat zones and implement appropriate regulations for restricting future development and redevelopment in each zone. For instance, regulations might allow rebuilding of structures in an "accommodation zone," but only if they are raised or otherwise built to withstand rising seas. Likewise, a "retreat zone" might include setbacks and other redevelopment restrictions, such as requiring certain uses to end after a specific time period. Finally, a "protection zone" could allow protection strategies for properties that feature coastal dependent structures, such as harbors.

An overlay zone might also include additional strategies to promote responsible coastal adaptation. For instance, redevelopment in vulnerable areas could be limited through downzoning. This

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[48] Hendriks, *supra* note 26; Lester Kwiatkowski et al., *Nighttime Dissolution in a Temperate Coastal Ocean Ecosystem Increases under Acidification* 6 SCIENTIFIC REPORTS 1 (2016).

[49] Elizabeth McLeod et al., *A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2* 9 FRONTIERS IN ECOLOGY AND THE ENVIRONMENT 552.

[50] Capitola currently uses several overlay districts in its zoning classifications. *See, e.g.*, CAPITOLA CITY, CAL., MUNICIPAL CODE §17.20.010 (affordable housing overlay district).

[51] A building moratorium could be put in place while overlay zones are developed. The building moratorium could encompass all areas that might be included in these zones. *See* CAL. GOV. CODE § 65858 (outlining procedures for local governments adopting interim ordinances as urgency measures).

[52] CAPITOLA CITY, CAL., MUNICIPAL CODE §17.50.090.

strategy rezones land to less intensive uses. Currently, the properties at the greatest risk of flooding and rising seas in Capitola are those close to Soquel Creek. These properties are currently zoned for several different land uses and could be prioritized for efforts to downzone.[53] Downzoning would lead to nonconforming uses in the short term—i.e., uses not allowed under the new zoning ordinances, but nonetheless "grandfathered" in because they existed prior to the downzoning. Regulations can be framed to allow these nonconforming uses initially but require them to cease after some period of time.

To achieve these longer-term coastal adaptation strategies, Capitola could consider taking several proactive steps in the short term. For instance, retreat strategies require that uplands be identified and purchased to make space for relocated structures. Land banking properties now could satisfy this future need.[54] Since these lands might not be used for this purpose immediately, this strategy could proceed gradually through phased and voluntary purchases of suitable upland properties. If this strategy does not succeed, or if the timeline becomes more urgent due to rising seas, it could be accomplished through eminent domain.[55] Likewise, Capitola could use transfers of development rights (TDRs) (where landowners sell the rights to develop their property) of vulnerable properties to help facilitate retreat.[56] This strategy could monetarily incentivize coastal landowners to provide their properties for retreat, and it could keep undeveloped coastal land undeveloped.

Capitola's existing coastal protection structures might also be studied to determine their efficacy and need for replacement or removal. Capitola's large sandy beach currently relies on two rip-rap groins on its east end to accumulate sand. To facilitate managed retreat, some of the existing coastal protection structures might need to be phased out. Others might need to be replaced if they are deemed necessary to coastal protection and provided they fit within Capitola's overall coastal adaptation strategy now and in the projected future.

Barriers and Considerations

There are several considerations that should be taken into account when moving forward with any of these coastal adaptation strategies in Capitola. First, limited undeveloped land is available immediately upland of the vulnerable areas, limiting retreat options in the area. As a result, businesses and residences that relocate might have to be moved farther inland than would be necessary elsewhere on the coast. Furthermore, the vulnerability of properties on bluffs and cliffs are less predictable than those along the lower-lying coastline, making long-term planning in these areas more challenging.[57]

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[53] *See* Figure 6.
[54] Land banking is the buying of land for some future use. Michael Allan Wolf, *Strategies for Making Sea-Level Rise Adaptation Tools "Takings-Proof"* 28 J. LAND USE & ENVTL. L. 157, 182 (2013).
[55] Eminent domain is the power of the government to take land for a public purpose. This power is limited by the U.S. Constitution and the California Constitution. U.S. CONST. AMEND. V; CAL. CONST. ART. I § 19.
[56] JESSICA GRANNIS, ADAPTATION TOOL KIT: SEA-LEVEL RISE AND COASTAL LAND USE 57-60 (2011).
[57] Cliffs and bluffs are more vulnerable to episodic erosion than beaches, which alternatively face constant erosive pressures. *See, e.g.*, episodic erosion events at Pacifica Lands End Apartments.

Takings concerns routinely arise when local governments undertake proactive planning for rising seas.[58] To avoid takings concerns, restrictions could be tailored to avoid depriving property owners of all economic value of their parcels.[59] Furthermore, restrictions could account for the economic lives of properties to avoid takings concerns, or could be grounded in avoiding and abating nuisances. Furthermore, any building moratoria could be tailored to be temporary.[60]

Third, regarding zoning classifications, any changes to the current classifications would likely include a grandfather provision allowing existing nonconforming uses to continue.[61] If grandfathering provisions are included in new ordinances, downzoning would only immediately affect undeveloped properties or properties whose uses have been abandoned. But, "grandfathered" provisions could be written to require landowners to comply with new zoning restrictions after a landowner renovates or rebuilds on his property, or when s/he changes the use.[62] Furthermore, as explained above, nonconforming uses could only be allowed for a certain period of time, after which they must cease.

Finally, cost and ecological drawbacks of proposed coastal adaptation strategies are necessary considerations when planning coastal adaptation strategies in Capitola. Cost is an important consideration because Capitola is highly developed and much of its vulnerable areas are in private ownership. Some parcels will be more expensive to buyout or pay just compensation for than others. Likewise, buyouts of private property might be less feasible than comparable options involving state or city lands. Property buyouts to facilitate relocation and to promote retreat face similar concerns. Likewise, cost versus long-term benefits of competing coastal adaptation options should be considered. Similarly, the ecological drawbacks of strategies such as beach nourishment should be weighed against their cost and their relatively short-term effectiveness.

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[58] Governmental taking of private property for public good—as well as regulations that "go too far" and result in "regulatory takings"—are common themes and constant considerations that arise when considering coastal adaptation strategies that require retreat from increasingly dangerous coastlines due to rising seas. Penn Coal Co. v. Mahon, 260 U.S. 393 (1922).

[59] Lucas v. South Carolina Coastal Council, 505 U.S. 1003 (1992).

[60] Tahoe-Sierra Preservation Council, Inc. v. Tahoe Regional Planning Agency, 535 U.S. 302 (2002).

[61] *See, e.g.,* CAPITOLA MUNICIPAL CODE § 17.50.310 ("A structure which was lawful before enactment of this chapter, but which is not in conformity with the provisions of this chapter, may be continued as a nonconforming structure subject to the following condition: if any nonconforming structure is destroyed by flood, earthquake, tsunami or, for another cause to the extent of fifty percent or more of its fair market value immediately prior to the destruction, it shall not be reconstructed except in conformity with the provisions of this chapter.").

[62] Local governments may end nonconforming uses in a variety of ways. Declare nuisance, pay just compensation, or require use to stop after a date certain. CECILY TALBERT BARCLAY & MATTHEW S. GRAY, CALIFORNIA LAND USE & PLANNING LAW 60-61 (2016).

Moss Landing: Coastal Setting

Moss Landing's relatively undeveloped coastline, surrounded by large tracts of farmlands, provides more adaptation options than other more densely populated sections of the coast. The shores surrounding Moss Landing are lined with high dune and sandy beach habitats extending north to Rio Del Mar and south to the edges of the city of Monterey.[63] This area includes many state beaches as well as local beach access points. Sediment for these beaches originates from rivers draining into the Monterey Bay.[64] Just inland of Highway 1, Elkhorn Slough drains the seasonal creeks and rivers that supply water to the surrounding agricultural areas, creating a network of wetlands and estuaries of gradually changing salinity.[65] Within the estuary, eelgrass and salt marsh habitats are prevalent. Much of this area is part of the ESNERR or the California network of Marine Protected Areas. While agriculture often runs up to the boundaries of arable land, most public recreational access to the water is constrained to a few entry points in local parks or at the Moss Landing Harbor.

Fig. 7: Satellite image of Moss Landing.

Moss Landing is the center point of the Monterey Bay coastline and is adjacent to diverse natural systems, including extensive wetland habitats in nearby Elkhorn Slough, sand dunes along the open coast, and sandy beaches north and south of the harbor mouth. Along with this connection to multiple natural systems, Moss Landing is a primary commercial and party-boat fishing hub for the central California coast with landing locations for market squid, rockfish, crab, lingcod, groundfish and other fisheries. Moss Landing also functions as a key marine research center due to the confluence of ecosystems and direct access to the deep Monterey Submarine Canyon.[66]

Moss Landing: Protective Role of Habitats

The dune and beach systems starting just north of Moss Landing and continuing south to Monterey play a greater protective role relative to the full study area extent.[67] The orientation of the coastline in the Moss Landing study area, which directly faces predominant incoming waves, is a significant driver of exposure in this region. In addition, coastal geomorphology and low elevation contribute to high exposure index scores in this location, meaning that existing habitats are critical to countering this relatively high exposure to hazards. Model results indicate that the presence of wetlands can reduce wave heights and associated damages to property from storm events. Coastal wetlands are not as effective at reducing erosion in areas of high wave energy.[68] The Moss Landing coastline is a high wave energy environment and the wetlands in this area play a moderate role in reducing coastal exposure to erosion and inundation during storms compared to the large dune

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[63] *See* Figure 7.
[64] *See* U.S. ARMY CORPS OF ENGINEERS, *supra* note 9.
[65] A key concern in this area is the historic changes in groundwater levels in the Pajaro and Salinas Valleys. These changes are further exacerbated by the effect of saltwater intrusion on highly productive agricultural lands as well as domestic potable water quality.
[66] Monterey Bay Aquarium Research Institute (MBARI) and Moss Landing Marine Labs (MLML) are two primary centers for marine research in the region.
[67] *See* Figure 7.
[68] Gedan, *supra* note 38.

systems. Loss of wetland habitat with rising seas will affect agriculture lands near Moss Landing. These wetland areas are highly exposed to waves mainly due to their large extent and proximity to the coastal zone.

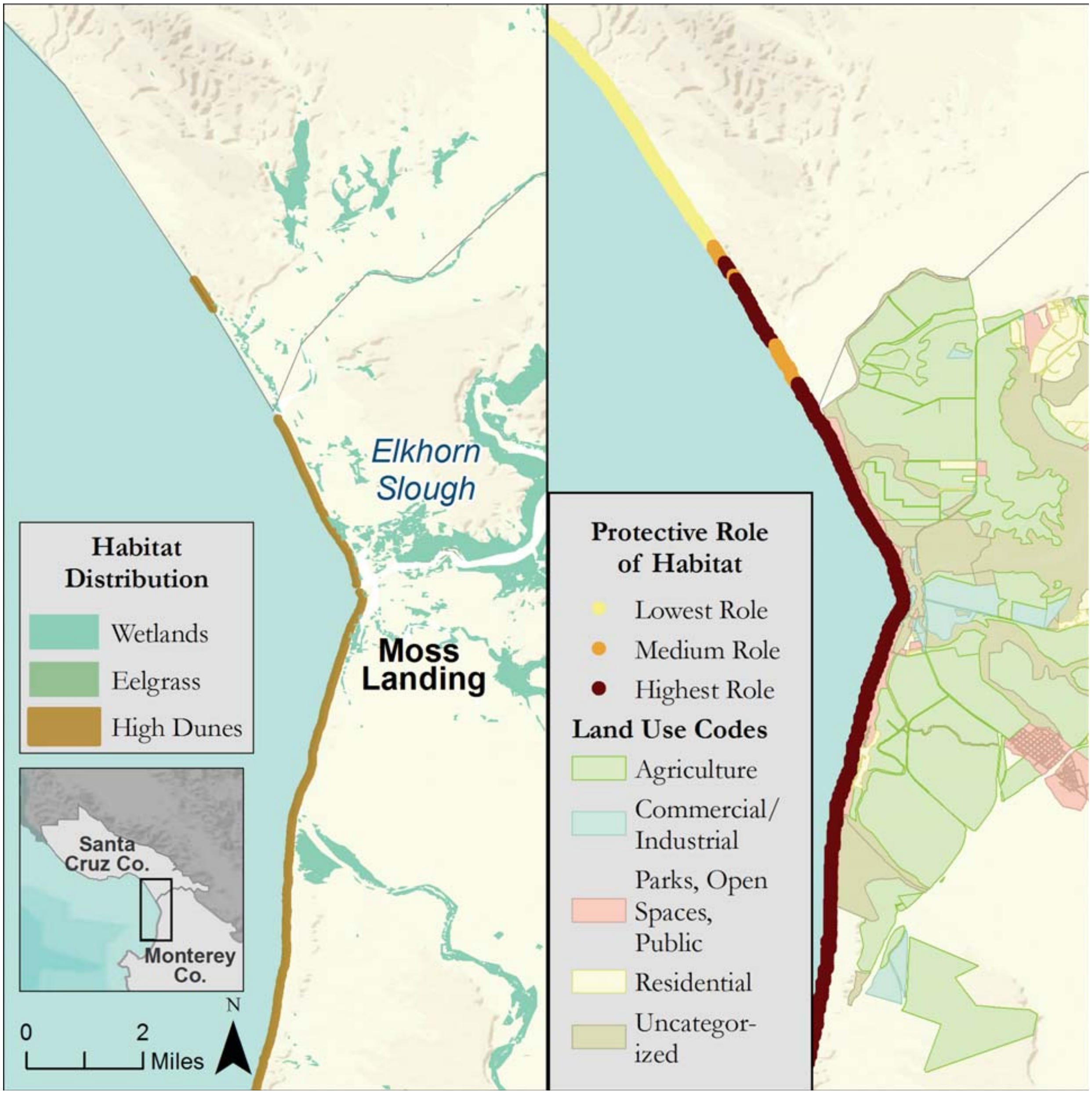

Fig. 7: Coastal habitats around Moss Landing, CA (Left). The relative role of coastal habitats near the mouth of Elkhorn Slough in reducing exposure to erosion and inundation with relevant land use zoning information (Right). Zoning information was distilled using the same methodology used for Capitola (Fig. 5).

Moss Landing: Ecosystem Services of Coastal Habitats

Coastal Dune and Beach Systems

The relatively dry areas on the high beach behind dunes are sheltered from wind and spray, serving as nesting grounds for endemic shorebirds and haul out spots for marine mammals. These beaches provide opportunities for coastal recreation, fishing, and wildlife viewing in the surrounding area in addition to their role protecting the coastline from high energy waves.

Elkhorn Slough

The estuarine system of Elkhorn Slough is the largest marsh habitat in California outside of San Francisco Bay and provides critical habitat for shorebirds and fishes. This area has also been home to a suite of competing human uses for more than 150 years (e.g., agriculture, cattle grazing, railroad and road construction, fishing, municipal energy production, marine research, tourism, recreation) that have led to the historical development of engineered structures (e.g., levees, embankments) and the construction of Moss Landing Harbor at the mouth of the estuary. These engineered structures have significantly influenced the structure and function of the estuarine system.[69] While the wetland systems in Elkhorn Slough are an ecologically and economically important feature of the area, they are also at risk due to a squeeze between rising sea levels and little room to migrate inland.[70]

Wetland habitats provide a number of key ecosystem services beyond coastal protection, including carbon sequestration, water quality improvement, flood abatement and biodiversity support.[71] The sheltered estuarine waters and seagrass meadows within the slough serve as a nursery for juveniles of commercially important fish species.[72] Elkhorn Slough is one of the few remaining freshwater and saltwater resting stops on the Pacific flyway. The slough is a critical habitat for migratory bird species and was designated a globally important bird area in 2000.[73] The banks of the Slough also serve as a major haul out area for marine mammals.

Additionally, wetland habitats store large amounts of carbon in their submerged soils when kept intact and have the potential to be used for carbon sequestration on the scale of decades or longer.[74] On a more immediate time scale, coastal vegetation helps buffer against ocean acidification by removing carbon dioxide from the water.[75] As larval fish and invertebrates experience more harmful effects from acidifying water conditions than adults, the wetlands and marshes of Elkhorn Slough may aid in protecting important species from harmful water chemistry in addition to protecting them from predators.[76]

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[69] Eric Van Dyke & Kerstin Wasson, *Historical Ecology of a Central California Estuary*: *150 Years of Habitat Change* 28 ESTUARIES 173, 179 (2005); *see also* CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH (Jane Caffrey et al. eds., 2002).

[70] Kerstin Wasson et al., *Ecotones as Indicators of Changing Environmental Conditions: Rapid Migration of Salt Marsh–Upland Boundaries* 36 ESTUARIES AND COASTS 654 (2013).

[71] WORLD RESOURCES INSTITUTE, ECOSYSTEMS AND HUMAN WELL-BEING: WETLANDS AND WATER SYNTHESIS (2005) (a report of the Millennium Ecosystem Assessment).

[72] Michael Beck et al., *The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates* 51 BIOSCIENCE 633 (2001).

[73] CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH, *supra* note 23.

[74] Cloern et al., *supra* note 24; McLeod, *supra* note 49.

[75] Hendriks, *supra* note 26.

[76] Haruko Kurihara, *Effects of CO2-driven ocean acidification on the early developmental stages of invertebrates* 373 MARINE ECOLOGY PROGRESS SERIES 275 (2008); Philip Munday et al., *Replenishment of fish populations is threatened*

Wetland habitats are threatened in the Elkhorn Slough area—and throughout the state—due to increased erosion from rising sea levels and land use development (agricultural, urban and/or rural). Fertilizer from agricultural runoff contributes to eutrophication and massive algal blooms that smother native flora, while urban pollutants may impair water quality.[77] Wetlands and coastal dunes that are exposed to coastal hazards could potentially migrate upslope given a path free of barriers from coastal development or shoreline hardening.

Moss Landing: Adaptation Strategies & Considerations

Coastal Adaptation Options

Moss Landing's coastline lends itself to several nature-based adaptation strategies. For instance, because the dunes in the area play a large role in protecting Moss Landing's coastline, adaptation strategies that protect, restore and enhance these areas could be targeted to maintain the integrity of the area. A dune restoration and enhancement project currently provides protection for MBARI. Additional suitable areas for dune restoration in Moss Landing could be identified and prioritized based on the protective role of specific dune habitats as well as factors specifically relevant to the local planning community. Beach nourishment might also be used to stem beach loss and to buffer these important dunes from erosion. Wetland restoration is another nature-based solution possible for Moss Landing. Wetland restoration in the area would carry various possible co-benefits including: sequestration of carbon dioxide, maintaining these areas as corridors for gradual coastline retreat and providing protection against storm surges.

Other nature-based options might be suitable here as well. Conservation easements could be implemented in some of these areas, particularly those most vulnerable to rising seas. This strategy involves either paying a landowner not to develop vulnerable land, or the landowner agreeing to do so without compensation, or in exchange for some other incentive, such as a tax break. This strategy would ensure that undeveloped lands stay undeveloped, and it could help transition currently developed but threatened lands to undeveloped lands. Rolling easements are another attractive but controversial option.[78] These can be used to allow the sea to migrate inland while slowly requiring the removal of structures within some distance of the approaching sea.[79]

In addition to the nature-based options outlined above, Moss Landing's coastline might also be suitable for other coastal adaptation strategies. For instance, accommodation and armoring might be appropriate for Moss Landing because it features a number of coastal dependent structures, such as the Monterey Bay Aquarium Research Institute, the Moss Landing Marine Laboratories, the Moss Landing power plant, and various boating and fishing facilities. Any of these structures might be protected or raised, depending on building design and construction, the anticipated

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by ocean acidification 107 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE OF THE UNITED STATES OF AMERICA 12930 (2010).

[77] Brent Hughes et al., *Recovery of a top predator mediates negative eutrophic effects on seagrass* 111 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 36444 (2014).

[78] *See generally* Meg Caldwell & Craig Holt Segall, *No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast*, 34 ECOLOGY L.Q. 533, 535 (2007) (explaining that a rolling easement is "a device, rooted in statutory or common law or in permit conditions, that allows the publicly owned tidelands to migrate inland as the sea rises, thereby preserving ecosystem structure and function.").

[79] JAMES G. TITUS, ROLLING EASEMENTS (2011) *available at* https://www.epa.gov/sites/production/files/documents/rollingeasementsprimer.pdf.

building life cycle, end of use, and planned deconstruction. Furthermore, because of the various coastal-dependent buildings in the area, moveable structures could be installed and moved as needed in order to keep these structures on the coast as needed.

Other options can be pursued for undeveloped parcels in the area and existing structures that are not coastal dependent. Highway 1 could be moved inland or raised.[80] As was discussed for Capitola, an overlay zone could provide notice to the owners of vulnerable properties and restrict building and redevelopment in the area, as deemed appropriate. Furthermore, a moratorium on development could be imposed for some certain time period, while proactive coastal planning is pursued.

Moss Landing has a large amount of surrounding undeveloped and agricultural land.[81] Accordingly, some of these open spaces may be appropriate, stable sites for managed retreat of buildings in the area. Buyouts might be necessary in certain areas where planning is not able to sufficiently address increasingly rising seas.[82] Transfers of development rights might also be appropriate in certain similar circumstances.[83]

Barriers and Considerations

This area of the coastline is dominated by water, protected areas and sensitive ecosystems. The abundance of seawater and wetland areas might pose challenges for coastal adaptation for several reasons. For instance, the abundance of inland waterways and wetlands means that there is not much land immediately upland to move vulnerable buildings via managed retreat. Additionally, while this area features many coastal dependent facilities that might be protected or raised, there are drawbacks to pursuing these strategies. For instance, raising structures might bring additional regulatory requirements, such as those imposed by the Americans with Disabilities Act.[84]

Developing coastal adaptation strategies for coastal dependent structures carries with it its own set of unique challenges. Coastal dependent structures are prioritized for coastal land use under the Coastal Act.[85] Coastal dependent structures are not a high priority to move upland because of their dependence on water, but they need to be protected from rising seas nonetheless. Leaving these coastal dependent assets where they are makes them more susceptible to massive storm events than slowly rising seas. However, protecting these structures by armoring with seawalls would exacerbate erosion around these protective structures. If these coastal dependent structures are armored in the short term, long-term plans should be made to remove the armoring and move the structures.

Moving or raising Highway 1 presents issues as well. While raising Highway 1 in place is a possible short-term solution, Highway 1 may eventually need to be moved inland due to rising seas and repeated storm events. Moving Highway 1 immediately landward of its current location also presents drawbacks. Inland relocation would put it right in the middle of protected areas such

[80] The issues with this proposition are discussed *infra* in the Barriers and Considerations section.
[81] *See* Figure 7.
[82] *See, e.g.*, New York's Recreate NY Smart Home Buyout Program.
[83] *See, e.g.*, Penn Central Transportation Co. v. New York City, 438 U.S. 104 (1978).
[84] 42 U.S.C. §§12101-12213.
[85] CAL. PUB. RES. CODE §§ 30235 & 30255.

as Elkhorn Slough[86] and could restrict coastal access.[87] Moving Highway 1 would also require CalTrans to exercise its eminent domain authority, which can be controversial. Finally, moving Highway 1 to upland areas, such as those currently used for agriculture, will introduce additional complexities because of how these lands are currently prioritized in the current LCP.[88]

Managed retreat faces several challenges in this area. While Moss Landing is surrounded by open area, much of the region comprises wetlands or otherwise sensitive or protected areas. For instance, the area features Elkhorn Slough State Marine Conservation Area, Elkhorn Slough State Marine Reserve, Moro Cojo Slough State Marine Reserve, Moss Landing State Beach, and the Moss Landing Wildlife Area. The abundance of state lands and conservation lands creates challenges for managed retreat. On the other hand, public and open spaces might be well-suited for conservation easements such that they are set aside to become inundated and form new wetland and marsh areas. Section 30240 of the Coastal Act protects environmentally sensitive habitat areas (ESHAs), and further complicates using any of the areas surrounding these protected areas in Moss Landing for managed retreat.[89]

Another issue is possible challenges to zoning changes in the area. Property owners affected by new regulations sometimes claim that these regulations impermissibly "take" their property without just compensation. As was the case for Capitola, local governments should be weary of enacting regulations that possibly deprive property of all of its economic value and of instituting moratoria that do not specify end dates.

<u>Summary</u>

Communities in the Monterey Bay region, like many areas of California and the nation, are actively planning for a changing climate. Rising sea levels and increasingly damaging storm events are expected to cause increased erosion and inundation, which will further threaten people, property, infrastructure and coastal habitats. If these habitats are lost, degraded or unable to adapt by migrating inland, then local communities also lose the beneficial services they provide, including carbon sequestration, improving water quality, buffering ocean chemistry, providing nursery or nesting grounds, and protecting from erosion and inundation.

Proactive adaptation planning that takes into account the role of coastal habitats—coupled with advanced construction designs and technologies—and policy pathways for implementation, will allow local communities to proceed from planning to implementation more effectively. Ultimately, this approach—in concert with similar coastal adaptation decisions throughout California—can lead to coastal management processes that are consistent for statewide needs and flexible for local needs while ensuring a vibrant coastline for future generations.

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[86] *See* list of protected areas in region *supra* note 15.
[87] The Coastal Act seeks to protect and maximize public coastal access. CAL PUB. RES. CODE. § 30211.
[88] MONTEREY COUNTY, NORTH COUNTY LAND USE PLAN 45-49 (1982).
[89] CAL. PUB. RES. CODE § 30240.

Habitat Type	Relative Protective Role*	Protective Attributes	Additional Ecosystem Services	Management Options
Kelp Forests	Relatively Low Role	Kelp forests attenuate low-energy wave action and have a dimished protective role as wave power increases.	Habitat for commercially viable fish and invertebrate species	Maintain healthy water conditions for kelp growth and reproduction.
			Vegetation harvested for commercial abalone aquaculture	
			Nutrient and vegetation export to local beach ecosystems	
			Integral ecosystem for culturally important species	
Wetlands	Relatively Moderate Role	Wetland ecosystems absorb water to reduce inundation and also serve to dissipate wave energy.	Flood control from inland inundation	Consider conservation of key areas of vegetation and soils before allowing development.
			Nutrient and sediment retention for improved water quality	
			Habitat for diverse species including marine mammals	Provide space for habitat to migrate inland as sea level rises.
			Carbon sequestration	
Seagrass	Relatively Low Role	Eelgrass beds attenuate low-energy waves which help decrease erosion of loose soils.	Wave attenuation	Provide space for habitat to migrate inland as sea level rises.
			pH buffer	Conserve existing habitat and restore damaged submerged aquatic vegetation.
			Nursery and essential habitat for fish and invertebrate species	
			Carbon sequestration	Maintain healthy water conditions and limit habitat degradation.
High Dune Systems**	Relatively High Role	Large dune systems dissipate high-energy waves and resist runup from powerful storms.	Cultural and aesthetic attachment	Maintain dune structure and vegetation.
			Location for recreation	
			Habitat for important bird and plant species	Regulate and/or limit dune sediment extraction.
Low Dunes & Beaches**	Relatively Moderate to High Role	Low dune systems and beaches dissipate low and moderate energy waves.	Habitat for important bird and plant species	Limit the implementation of built structures that impede migration of beach systems.
			Location for recreation	
			Cultural and aesthetic attachment	Maintain beach structure and access to continued sediment supply.

Table 1: Compilation of Ecosystem Services

*Protective role is based on model outputs created for and relative to the full study area (Año Nuevo to Wharf 2).
**Dunes were classified as “high dune” if their crest was higher than five meters. High dunes are less likely to lead to overwash and inundation from coastal storms.

Adaptation Strategy	Definition*	Example**	Potential Applications	Role of Natural System
Protection: *Hold the Line*	Employ built measure to defend development in current location	Wetland Restoration	Elkhorn Slough; northern section of Moss Landing Harbor; potentially in creeks near Capitola	Enhances extent of ecologically important natural areas
		Dune Restoration	North and south of Moss Landing on outer coast; southern Monterey Bay	Enhances extent of ecologically important natural areas
		Beach Nourishment	Soquel Creek Lagoon; outer coast of Moss Landing	Adds to natural system; requires thorough environmental monitoring
		Hard Protection	Near coastal-dependant or critical infrastructure such as power plant or critical transportation routes	Often limits natural habitat migration and increases erosion at edges of armoring
Accommodation: *Adjust to the line*	Modify existing or new development to decrease hazard risks	Overlay Zones	Existing flood zones or areas expected to be impacted by rising sea levels	N/A
		Limit Redevelopment	Locations that encounter repetitive loss or in (newly delineated) sea level rise overlay zones	May facilitate migration of natural systems or allow them to reestablish themselves
		Mobile Structures	Structures that are location dependent yet also encounter large episodic flood events	N/A
		Conservation Easement	Open and undeveloped areas in existing flood plain and areas adjacent to flood plains	Keeps natural system intact
Retreat: *Get away from the line*	Relocate existing development out of hazard areas and/or limit construction of new development in vulnerable areas	Planned Retreat	Highly vulnerable areas or locations with suitable upland areas available nearby	Removes structures allowing corridor for habitats to naturally migrate inland
		Buyout Programs	Lands suitable for becoming open areas	Can help promote natural system to replace previously developed area
Hybrid: *Maintain a flexible line*	Using strategies from multiple categories that may need to change over time	Accommodate over short term; relocate over long term	Hybrid adaptation options could be designed with enough flexibility to be applied across many different areas as needed	Provides pathway for taking actions that allow habitat to migrate and may provide opportunities for nature-based solutions
		Update land use designations and zoning ordinances		
		Redevelopment restrictions		
		Permit conditions		

Table 2: Compilation of Adaptation Strategies

* Definitions of adaptation strategies are distilled explanations derived from chapter seven of the California Coastal Commission's Sea Level Rise Guidance (Guidance).

** Many examples are summarized descriptions from figure 17 of the Guidance.

Analysis, Methodology, and Assumptions

This assessment involved a combination of ecosystem service modeling and adaptation policy research in an effort to identify and map priority locations for nature-based strategies that reduce vulnerability of critical assets using feasible land use policy methods.

To map and value the goods and services from natural habitats, we used the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) free and open-source suite of software models created by the Natural Capital Project at Stanford University. The InVEST Coastal Vulnerability model incorporates a scenario-based approach to evaluate the role of natural habitats in reducing exposure to coastal impacts. [90] The InVEST Coastal Vulnerability model produces a qualitative estimate of coastal exposure. The Exposure Index differentiates areas with relatively high or low exposure to erosion and inundation during storms.

Data inputs included: 1) **Geomorphology**: Polyline representing coastal geomorphology based on the National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index; 2) **Coastal habitat**: Polygons representing the location of natural habitats (e.g., seagrass, kelp, wetlands, etc.) from the Department of Fish and Wildlife website created for Marine Life Protection Act process; 3) **Wind and wave exposure**: Point shapefile containing values of observed storm wind speed and wave power across an area of interest using Wave Watch III data provided by NOAA; 4) **Surge potential**: Depth contour that can be used as an indicator for surge level default contour is the edge of the continental shelf. In general, the longer the distance between the coastline and the edge of the continental shelf at a given area during a given storm, the higher the storm surge; 5) **Relief**: A digital elevation model (DEM) representing the topography and (optionally) the bathymetry of the coastal area—this analysis includes a five meter bathymetric and topographic merge from US Geologic Survey for the California coast; 6) **Sea-level rise**: Rates of (projected) net sea-level change derived from the National Research Council 2012 report (highest range for 2030: 12" of sea level change);[91] 7) **Hard Armoring**: Data set inventory of man-made structures and natural coastal barriers that have the potential to retain sandy beach area in California. This armoring dataset is a compilation of the UC Santa Cruz Sand Retention Structures, Monterey County Barriers, and US Army Corps of Engineers Coastal Structures.

One main limitation with this modeling approach is that the dynamic interactions of complex coastal processes occurring in a region are overly simplified into the geometric mean of seven variables and exposure categories. InVEST does not model storm surge or wave field in nearshore regions. More importantly, the model does not take into account the amount and quality of habitats, and it does not quantify the role of habitats for reducing coastal hazards. Also, the model does not consider any hydrodynamic or sediment transport processes: it has been assumed that regions that belong to the same broad geomorphic exposure class behave in a similar way. In addition, using this model we assume that natural habitats provide protection to regions that are protected against erosion independent of their geomorphology classification (e.g., rocky cliffs). This limitation artificially deflates the relative vulnerability of these regions, and inflates the relative vulnerability

[90] INTEGRATED VALUATION OF ECOSYSTEM SERVICES AND TRADEOFFS, http://www.naturalcapitalproject.org/models/coastal_vulnerability.html (last visited Aug. 30, 2016).

[91] NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON SEA LEVEL RISE IN CALIFORNIA, OREGON, AND WASHINGTON, SEA-LEVEL RISE FOR THE COASTS OF CALIFORNIA, OREGON, AND WASHINGTON: PAST, PRESENT, AND FUTURE (2012).

of regions that have a high geomorphic index. Based on these limitations and assumptions, the InVEST Coastal Vulnerability tool is an informative approach to investigate *relative exposure* for a coastline and identify locations where coastal habitats play a relatively significant role in reducing exposure. However, for local scale decisions regarding locally specific geomorphic conditions, further analysis is needed (e.g., the InVEST Nearshore Wave and Erosion model).

Results can help evaluate tradeoffs between climate adaptation strategy approaches. In this assessment, we compared the InVEST Exposure Index results both with and without the protective services provided by natural habitats. This approach (computing the difference between exposure indices) provides a priority index for locations in which coastal habitats play the largest relative role in reducing exposure to erosion and inundation. These locations can then be further investigated for nature-based strategies to reduce vulnerability.

We began our policy research by exploring academic and practitioner guidance on potentially appropriate coastal adaptation strategies for sea-level rise. We reviewed a number of guidance documents that outline land use planning and regulatory options that should be considered in coastal areas. Next, we identified how priority or high-risk locations align with various land-use or zoning designations in Monterey and Santa Cruz Counties using land use zoning layers provided by Monterey and Santa Cruz Counties as well as from planning staff from the City of Capitola. The zoning designations and population density in the various high-risk areas guided our determination of the strategies most feasible in each location. For example, high-density zoning designations—in most cases—reduce the feasibility of habitat restoration or retreat options. We also researched relevant state- and county-level laws and policies on acceptable strategies for near- and long-term adaptation to rising sea levels. We identified the limitations these policies place on adaptation options in the Monterey Bay Region and explored potential changes to the existing policies that may increase adaptive capacity. Ultimately, these prioritized policy considerations may be relevant to both Santa Cruz and Monterey Counties—as well as local jurisdictions—through the development of the Local Coastal Program update process.

In addition to this specific engagement in the Monterey Bay Region, the Center for Ocean Solutions is also involved in Local Coastal Program updates throughout the state. The Center is playing a key role in compiling, distilling, and distributing information on incremental adaptation actions with current county partners (i.e., Sonoma, Marin, Santa Cruz, and Monterey Counties) as well as with the State Coastal Conservancy and California Coastal Commission through the development of the California Coastal Adaptation Network. By developing a transferable methodology that incorporates the role of natural capital into county-level coastal adaptation planning, the Center for Ocean Solutions is scaling these best practices to a statewide prioritization of adaptation strategies that preserve the integrity of natural systems. The Center's work advances the state's efforts for flexible consistency in accordance with the California Coastal Commission's Sea Level Rise Policy Guidance.

Appendix B.

Climate Change Impacts to Combined Fluvial and Coastal Hazards (ESA, 2016)

MONTEREY BAY SEA LEVEL RISE

Climate Change Impacts to Combined Fluvial and Coastal Hazards

Prepared for
Moss Landing Marine Labs with Funding from the
California Ocean Protection Council

May 13, 2016

MONTEREY BAY SEA LEVEL RISE

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1 INTRODUCTION

As part of the Sea Level Rise study for the Monterey County Local Coastal Program (LCP) ESA simulated and mapped the potential inundation from extreme coastal and fluvial conditions for multiple scenarios of future climate conditions. Two fluvial systems were analyzed for this effort (1) the Reclamation Ditch watershed which includes Gabilan Creek and Tembladero Slough the and drains to the Moss Landing Harbor, and (2) Soquel Creek which runs through the City of Capitola in Santa Cruz County. The Reclamation Ditch watershed is mostly agricultural while the lower reaches on Soquel Creek are mostly urbanized. These two systems were selected to enable risk assessment for a range of natural and manmade resources.

Climate data analysis was conducted to evaluate future extreme rainfall-runoff events and extreme coastal tide and wave events. For the rainfall-runoff and fluvial climate change analysis ESA used public climate model data to develop medium and high estimates of 100-year discharge for 2030, 2060, and 2100 time periods. ESA also developed estimates of extreme tide conditions with sea level rise for medium and high climate change scenarios for the three future periods. The flood levels and extents were then estimated for these scenarios using hydraulic modeling driven by combined watershed and coastal water level conditions under climate stress.

The study developed geospatial datasets for the extent and depth of inundation under flooding for existing conditions and future climate scenarios. The key products and findings for this study include:

- **Key products developed**
    - GIS layers of flood inundation extent for the Moss Landing Harbor and surrounding areas, and Soquel Creek in Capitola, for six scenarios (1) existing conditions 100-year flood, (2) future conditions 100-year flood under high emissions for 2030, (3 and 4) medium and high emissions for 2060, and (5 and 6) medium and high emissions for 2100.
    - GIS depth rasters for both systems and the six scenarios listed above.
    - Amendments to previously developed coastal flooding layers based on newly surveyed structural information in flooded areas in Monterey Bay.
    - Technical metadata and reporting contained herein
- **Key analysis findings**
    - Analysis of existing hydrologic climate data indicates an increase in peak flow for the 100-year discharge of 337 cfs (25%) for high emissions by 2100 on the Reclamation

Ditch system and by 1660 cfs (95%) for Soquel Creek for the same emissions and time horizon scenario.

- Analysis of existing sea level rise trends and anticipated coastal flood levels indicate an increase in downstream water level of 5.2 ft for high emissions by 2100.

- As anticipated the increase in rainfall intensity and 100-year discharge combined with the increase in sea level under climate change increases flood extent on both systems. In comparing the 100-year event under existing conditions with the year 2100 high-emissions scenario, the increase in flood extent for the Reclamation Ditch system is approximately 1736 acres (95%) and the change in flood depth is approximately 2.6 feet (36%). The same comparison for Soquel Creek, which is more topographically constrained, shows a total increase in flood extent of 65 acres (65%) and an increase in flood depth of 3.01 feet (29%).

The following four report sections lay out the technical analysis methodologies, flood hazard mapping results, and applications for the resulting information in planning and adaptation assessments. Specifically Section 2 describes the climate analysis conducted to develop boundary conditions for the hydraulic model for several scenarios representing change in 100-year discharge due to increased precipitation intensity and depth with climate change and the change in extreme ocean level coincident with the 100-year flow. Section 3 describes the model development process for both the Reclamation Ditch and Soquel Creek systems. Section 4 summarizes the flood hazard mapping analysis conducted to develop the geospatial datasets of flood hazard for the climate scenarios analyzed. Section 5 summarizes the applicability of the datasets to planning and adaptation efforts for the communities that may be at risk of additional flooding under stress by climate change.

2 CLIMATE ANALYSIS

2.1 Emissions Scenarios

The goal of the climate change data analysis was to review existing climate model data to estimate changes in extreme rainfall, coastal water level, and the resulting extent of flood hazards. The changes in extreme rainfall conditions were used to drive the inflow boundary for the hydraulic models of the two systems. Climate model data were evaluated for the latest set of General Circulation Models (GCMs) developed for the IPCC's fifth Assessment Report (AR5). The GCM data produced for AR5 has been aggregated by the World Climate Research Programme under the Coupled Model Intercomparison Project Phase 5 (CMIP5). The emissions scenarios used to drive the GCMs for CMIP5 are referred to as Representative Concentration Pathways (RCPs). The highest scenario, RCP 8.5, reflects a track with little mitigative measures to reduce greenhouse gas emissions resulting in a net increase in radiative forcing of 8.5 W/m^2 by 2100 relative to pre-industrial conditions. A medium level emissions scenario, RCP 4.5, reflects a future wherein changes in technology and energy usage stabilize the increase in net radiative forcing to 4.5 W/m^2 by 2100. These emissions scenarios, RCP 4.5 and RCP 8.5, were used to reflect respectively medium and high emissions trajectories for this study. Existing conditions was also modeled which is representative of a low emissions scenario thus the scenarios selected effectively span low, medium, and high climate change conditions.

These emissions scenarios supersede the scenarios developed in the Special Report on Emissions Scenario (SRES) utilized for the IPCC's fourth Assessment Report (AR4) and used to drive GCMs for CMIP Phase 3 (CMIP3). In general, the RCP4.5 emissions scenario tracks closely with the prior SRES B1 scenario, while RCP8.5 tracks slightly above SRES A2. The following figure (Figure 1) compares the change in mean surface temperature for the SRES and RCP emissions scenarios.

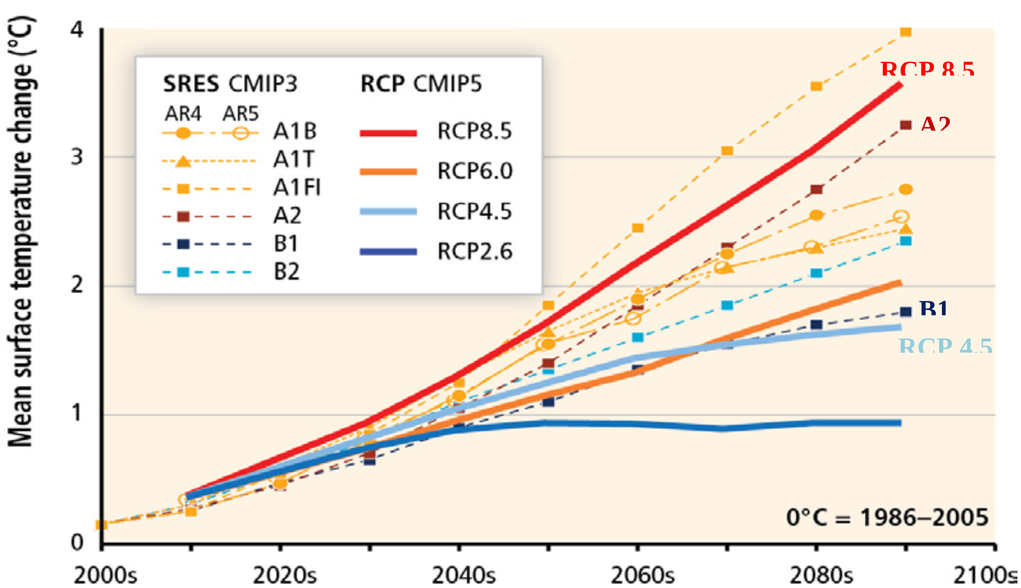

Figure 1. Comparison between SRES and RCP emissions scenarios. Reproduced from Figure 1-4 of IPCC AR5, WGII, Chapter 1

2.2 Extreme Fluvial Streamflow Analysis

Model output from GCMs driven by the RCP emissions scenarios was downscaled by CMIP5 institutions to regionalize the data from a global scale to higher resolution local scale. The downscaled data were then used to drive hydrologic models and estimate runoff for a daily timestep on a 12km x 12km grid from 1950-2100 in a study conducted by the USBR (2014). ESA used the resulting data from the USBR study to route baseflow and surface runoff and generate a time series of daily streamflow at the outlet of the two systems. The routing routine used is a component of the Variable Infiltration Capacity (VIC) model used in the USBR study to develop the runoff datasets.

The resulting daily streamflow time series from 1950-2100 was used to conduct flood frequency analysis to estimate 100-year discharge (Q_{100}) for medium and high emissions for 2030, 2060, and 2100. From the daily time series, peak annual flows were extracted for each year from 1950- 2100. A frequency curve was then fit to subsets of the peak annual flows using the Log Pearson III (LP-III) fitting method outlined in the USGSs Bulletin 17b (USGS, 1982). The USGS conducted a 2011 study updating many of the elements of Bulletin 17b based on updated gage records through water year 2006 for California gages (USGS, 2011). Two significant elements that were updated were the methods for estimating values for generalized skew (G_{gen}) and mean square error for generalized skew (MSE-G_{gen}) based on the average elevation of the basin. The average elevation of the basin is 479 feet for the Reclamation Ditch system and 1,141 feet for Soquel Creek. Based on the non-linear model for G_{gen} and the relationship between MSE-G_{gen} and average basin elevation summarized in USGS, 2011 Tables 7 and 8 respectively, the values estimated for G_{gen} and MSE-G_{gen} for the Reclamation Ditch watershed are -0.613 and 0.14, respectively, and -0.581 and 0.14 respectively for Soquel Creek.

Using these updated values in the LP-III method, we computed 100-year discharge for each GCM and each emissions scenario for an historical period, and three future time periods—2030, 2060 and 2100. A sample figure for the flood frequency curve for the historic time period for a single GCM for RCP4.5 is shown in Figure 2. Subsets of the data were selected for the time periods as summarized in Table 1.

TABLE 1
SUBSETS FOR TIME PERIODS USED IN FLOOD FREQUENCY ANALYSIS

Time period	Years for which peak annual flow was used in flood frequency analysis	Emissions scenario	GCM percentile	Resulting 100-year flow variable
2030	2015-2045	RCP 4.5 (medium)	50th	Q_{100}-2030-medium
		RCP 8.5 (high)	90th	Q_{100}-2030-high
2060	2045-2075	RCP 4.5 (medium)	50th	Q_{100}-2060-medium
		RCP 8.5 (high)	90th	Q_{100}-2060-high
2100	2070-2100	RCP 4.5 (medium)	50th	Q_{100}-2100-medium
		RCP 8.5 (high)	90th	Q_{100}-2100-high

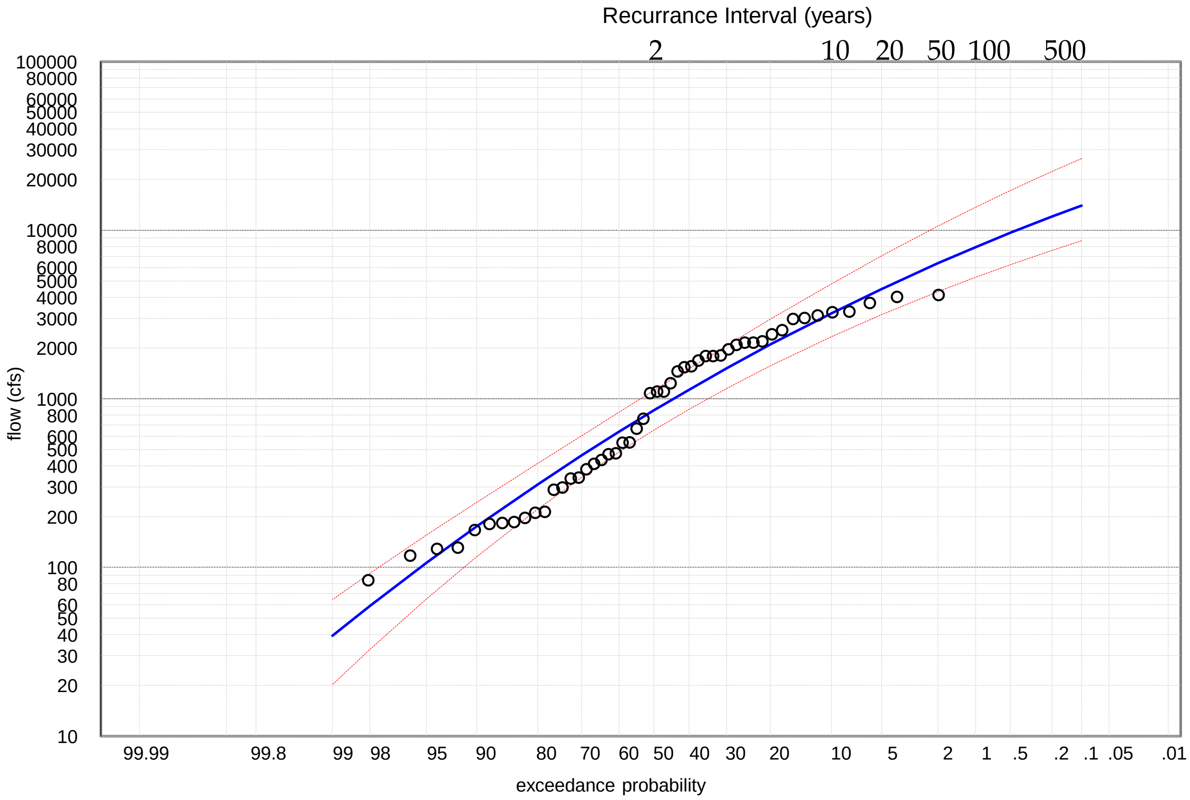

Figure 2. Log Pearson III flood frequency curve for historic time period (1950-2000) for GCM ACCESS[1] 1-0 for the RCP4.5 emissions scenario. The black dots show peak annual flow from routed GCM hydrology, the blue line shows the fitted LP-III curve, and the red lines show the 95- and 5-percent confidence intervals.

Because this analysis was conducted for each individual GCM, a distribution of GCMs can be created. The distribution highlights the discrepancy between individual models and the need to select a representative percentile for characterizing climate risk on any system. An example of the distribution of all models considered for a single emissions scenario and selected percentiles within the model distribution is shown for change in peak annual flow in Figure 3.

[1] Australian Community Climate and Earth-System Simulator (ACCESS)

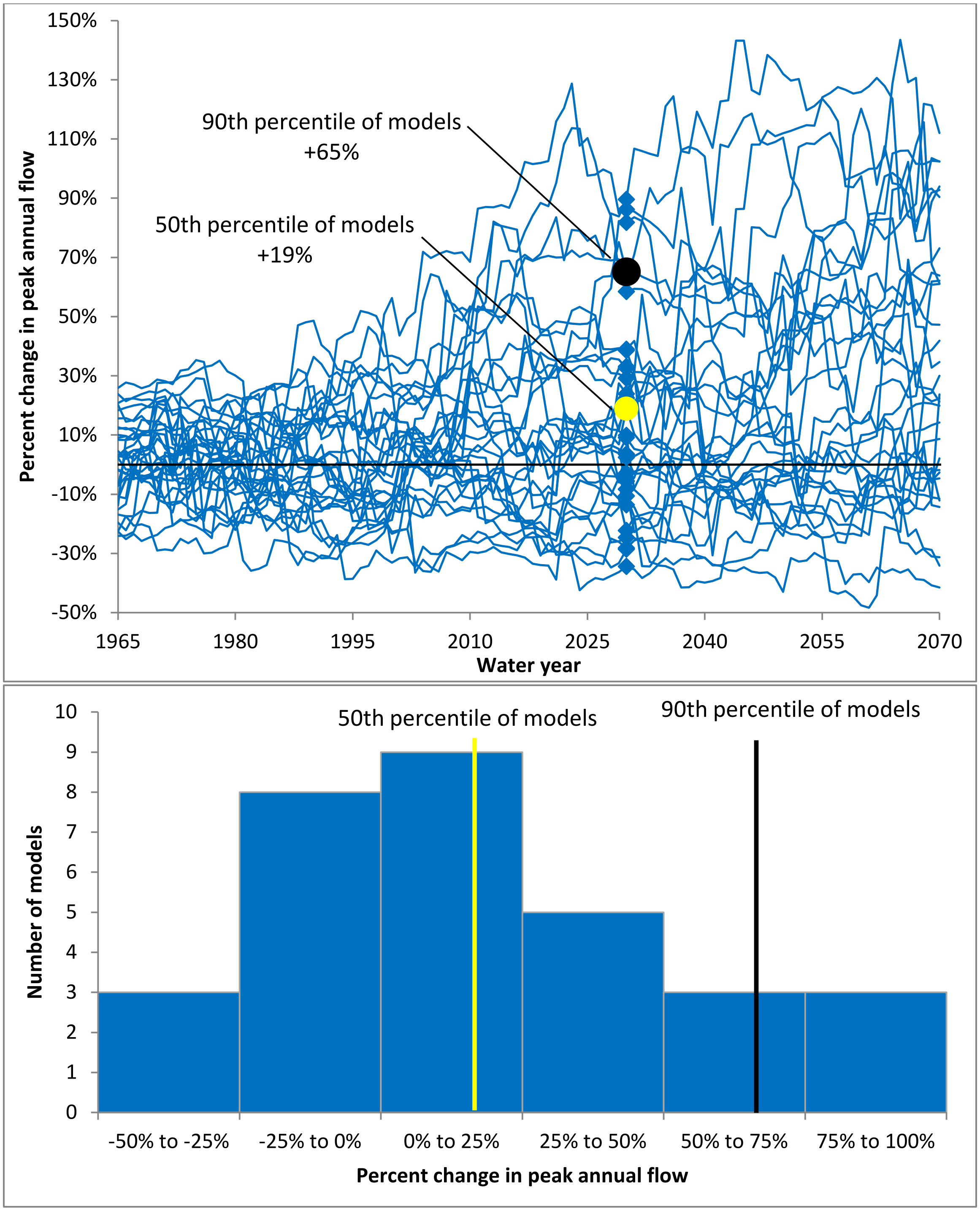

Figure 3. Percent change in peak annual flow relative to 1950-2000 average for all GCMs under RCP 4.5 emissions, blue lines show individual GCM trajectories and blue dots show result at year 2030 (top), and (bottom) histogram of total number of models for given ranges of percent change in peak annual flow

The 100-year discharge and the change in 100-year discharge for the three future time periods relative to the historic time period was calculated for each GCM based on the following equation:

$$\Delta Q_{100} = Q_{100-year-emissions} - Q_{100-hist}$$

Where ΔQ_{100} is the change in Q_{100} in cfs

$Q_{100\text{-year-emissions}}$ is the Q_{100} for a given GCM at a specific time horizon and emissions scenario

$Q_{100\text{-hist}}$ is the Q100 for the historical time period based on the GCM data

The distribution of GCMs for the change in Q_{100} on the Reclamation Ditch is shown for RCP 4.5 in Figure 4 and for RCP 8.5 in Figure 5. The distribution of GCMs for the change in Q100 on the Soquel Creek is shown for RCP 4.5 in Figure 6 and for RCP 8.5 in Figure 7.

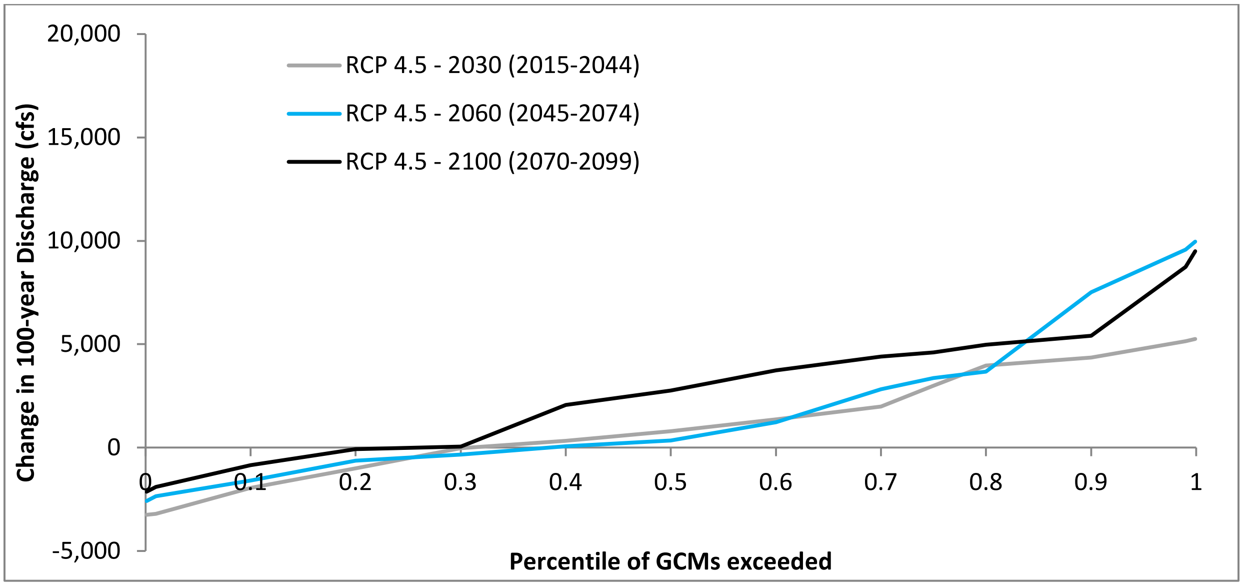

Figure 4. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 4.5 on the Reclamation Ditch System

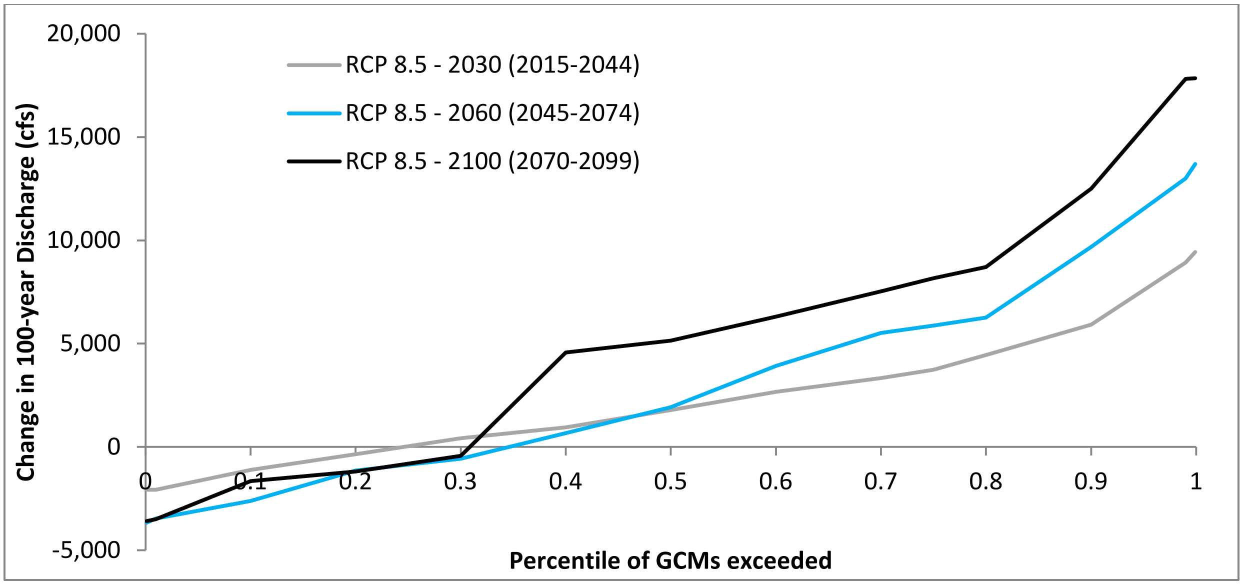

Figure 5. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 8.5 on the Reclamation Ditch

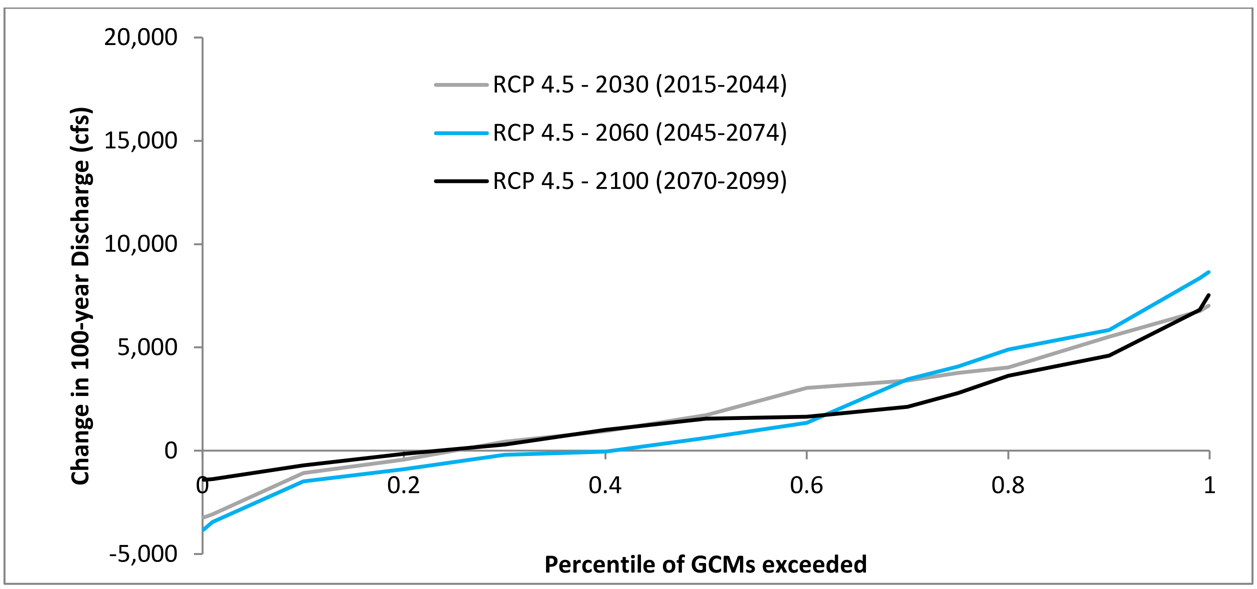

Figure 6. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 4.5 on Soquel Creek

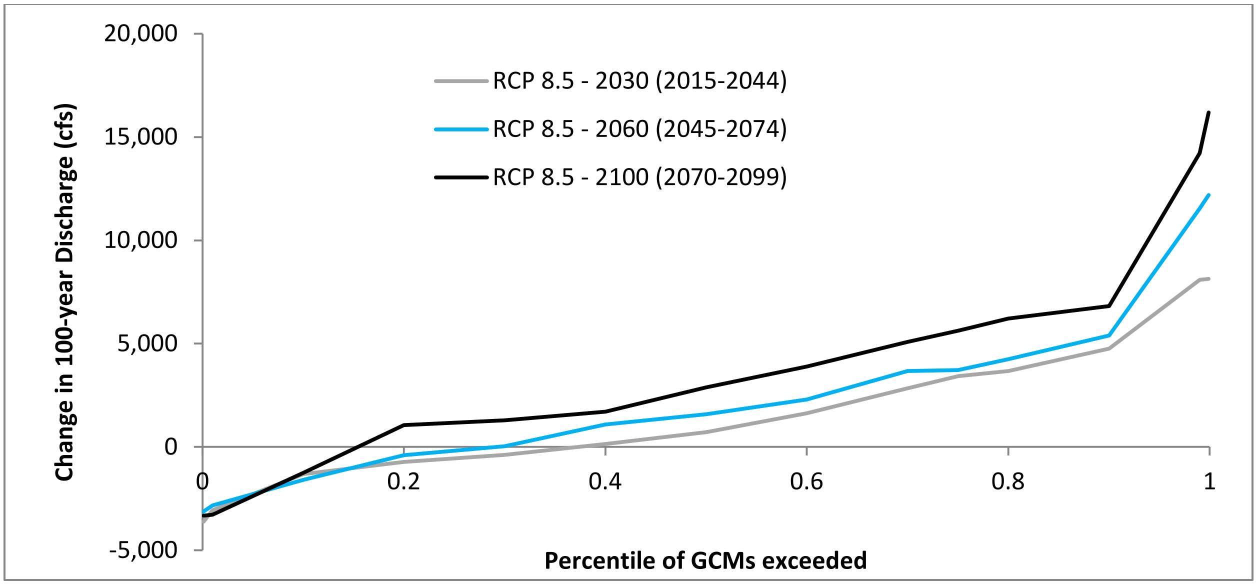

Figure 7. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 8.5 on Soquel Creek

These figures indicate that for RCP 4.5, the emissions scenarios are grouped fairly closely for each future time period. The 'medium' emissions scenario was estimated from approximately the 50th percentile for the three time periods for RCP 4.5. It was determined that the 90th percentile of the models for RCP 8.5 for each individual year would be used to represent the 'high' emissions scenario. The changes estimated for 100-year discharge for both systems are summarized in Table 2.

TABLE 2
CHANGE IN 100-YEAR DISCHARGE FOR BOTH SYSTEMS RELATIVE TO HISTORIC PERIOD (1950-2000)

	Reclamation Ditch system			Soquel Creek		
Emissions scenario	**2030**	**2060**	**2100**	**2030**	**2060**	**2100**
Medium (RCP 4.5 50th percentile)	20%	40%	60%	13%	15%	20%
High (RCP 8.5 90th percentile)	140%	210%	275%	62%	68%	95%

The flows estimated in the extreme streamflow analysis were used to drive the hydraulic models which, in turn, were used to map inundation extents for existing conditions and the five future climate conditions (2030 high, 2060 and 2100 medium and high emissions). In addition to the extreme streamflow change, the downstream coastal water levels are influenced by sea level rise. The following section describes the analyses conducted to characterize the extreme coastal water level that would be coincident with the 100-year flood.

2.3 Extreme Coastal Water Level Analysis

2.3.1 Reclamation Ditch Extreme Tide Levels

The ocean boundary condition from the existing unsteady HEC-RAS hydraulic model consisted of a repeated tide cycle that peaked at about MHHW. To represent extreme tide conditions we used a 10-year tide as the ocean boundary for existing conditions. Given that the mouth of this system (the mouth to Moss Landing Harbor) is relatively deep we assumed that the mouth would not support wave setup, and therefore no additional water level increase was added for wave setup. The input ocean stage hydrograph was scaled up to peak at the 10-year water level (7.69 ft NAVD, from Monterey NOAA Buoy 9413450).

For future conditions the 10-year tide was increased at the rate of sea level rise based on the CA Coastal Commission guidance document (CCC, 2013). The total amount of SLR added for each scenario was estimated by fitting curves to the NRC 2012 SLR values, following this guidance. The peak tide elevation for each scenario is summarized in Table 3. These are the same water levels used by ESA for the Monterey Bay hazard mapping (ESA PWA, 2014).

TABLE 3
EXTREME TIDE CONDITIONS FOR RECLAMATION DITCH SYSTEM

	Sea level rise (ft)		10-year tide level + SLR (ft NAVD)	
Time period	Medium	High	Medium SLR	High SLR
2015	-	-	7.69	
2030	0.3	0.7	8.0	8.4
2060	1.1	2.4	8.8	11.0
2100	2.9	5.2	10.6	12.9

2.3.2 Soquel Creek Extreme Tide Levels

The Soquel Creek model is steady state thus there is no time dimension to the peak coastal water level. Recognizing this, it was deemed not representative to use the 10-year peak water level to represent extreme tide levels given that this elevation is only reached for a brief period during the 10-year event. We selected the 1-year recurrence interval as a tide level that would have a long enough time dimension to be considered credibly steady-state during an extreme tide event. Based on the Monterey Bay tide gauge (NOAA# 9413450), the 99% exceeded (1-year recurrence) tide elevation is 6.87 ft NAVD. Additionally, given the geomorphic configuration of this system, we added an additional increase in the steady state boundary to account for storm surge and wave setup. We selected 2-feet to account for these factors based historic data and previous studies of joint probability between coastal storm surge and high intensity rainfall as described below.

The steady downstream water surface boundary condition for Soquel Creek was chosen based on review of traditional practice and consideration of past analyses of joint probability of peak river discharges with elevated ocean water levels. A past study on San Lorenzo Creek by (USACE 2011) showed a correlation between peak discharges and storm surges, with average tidal residuals during river flood events ranging from 0.4 to 1.5 feet and wave setup ranging from 0.2 to 2 feet. We also examined historic data for Soquel Creek and nearby Aptos Creek for coastal storm events based on USGS stream gauge, CDIP buoy, and NOAA tide gauge records to estimate the wave setup during past events. We found similar patterns in the tide residuals, wave setup, and tide peak elevation during the storm. The wave setup and tide peak for a set of extreme tide and flow events is summarized in Table 4. The tidal peak water level that occurred around the time of the peak river discharge was found to be near the 1-year recurrence elevation with an average residual 0.5 feet and average estimated wave runup of 1.2 feet.

TABLE 4
COASTAL STORM SURGE AND WAVE SETUP FOR EVENTS ON SOQUEL AND APTOS CREEKS

Creek	Date	Approximate peak flow (cfs)	Ocean Residual ft (1-day average)	Offshore Wave Height, H (ft) approx	Wave Setup hsetup (ft)[1]	Total ocean water anomaly (wave setup + residual) ft	Tide Peak During Storm (ft NAVD)
Aptos	2/6/1983	210	0.74	16	1.6	2.38	6.1
Aptos	2/25/1983	210	0.43	11	1.1	1.58	6.9
Aptos	2/23/2009	280	-0.04	7	0.7	0.7	5.6
Aptos	1/20/2010	210	1.17	21	2.1	3.3	6
Aptos	12/21/2010	310	0.65	10	1	1.63	7
Aptos	12/29/2010	140	0.23	16	1.6	1.87	6.3
Aptos	2/25/2011	n/a	0.12	8	0.8	0.94	5.6
Soquel	10/13/2009	4000	0.85	7	0.7	1.51	6.1

[1]steady (average) setup ~= 0.1*H

The future conditions 100-year discharge combined with the future conditions extreme coastal tide level were used as boundary conditions for the hydraulic modeling analysis. The modeling analysis is described in the following section.

3 HYDRAULIC AND HYDRODYNAMIC MODELING ANALYSIS

3.1 Reclamation Ditch Unsteady Modeling

The basis for the unsteady HEC-RAS hydraulic model was a model provided by the Monterey County Water Resources Agency (MCWRA) to ESA in 2014. The model is an updated version of the HEC-RAS model originally developed by Schaaf & Wheeler (1999) for flood analysis. The model has been periodically updated for flood mapping studies. However, the original channel data dates back to the original study. The existing conditions 100-year hydrology was also developed by Schaaf & Wheeler in 1999 using a HEC-1 hydrologic model for the Gabilan Creek watershed. This formed the basis for the existing conditions 100-year unsteady hydrograph boundary conditions used in the model. Updates to the model geometry required including positioning the model in real geospatial coordinates and updating overbank areas with LiDAR topography are described in the following section.

3.1.1 Model Geometry Development

Hydraulic Roughness – The parameter representing the resistance to flow within a channel or floodplain due to vegetation, bedform, and bed material is known as the manning's roughness or 'n' value. The manning's n values were adopted from the existing model. The values are 0.025 for channel roughness and 0.065 for floodplain roughness.

Georeferencing – The original model provided by Monterey County required georeferencing to spatially orient the model input and output. The original mode was shifted to correctly orient the confluence of the Tembladero Slough and drainage canal from Merritt Lake (just upstream of Castroville). Tembladero Slough was digitized from Moss Landing up the Reclamation Ditch to the Hwy 101 crossing in Salinas using the HEC-GeoRAS toolbar in ArcGIS and then imported to the HEC-RAS model. Cross section spacing was then adjusted in HEC-RAS to align known bridge crossings with their spatial location. The model layout is shown in Figure 8.

Figure 8. Reclamation Ditch hydraulic model layout

Update with LiDAR – Because the overbank representation of the existing model was limited, it was necessary to update the overbank topography from new sources. This was accomplished by first extending the channel cross sections to include the full floodplain and then updating the cross section station-elevation data with topography from the 2009-2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM that was downloaded from http://coast.noaa.gov/dataviewer/. This was only done for cross sections downstream of the railroad crossing west of Hwy 183, as the focus was primarily on flood behavior downstream. We determined that the elevations of the existing model were vertically referenced to an old vertical datum NGVD29. We thus converted the elevations to NAVD88 using the conversion factors listed in the FIS (+2.7 ft for Tembladero Slough, +2.77 ft for Reclamation Ditch). The model was also expanded into the Moro Cojo Slough and historic slough area between the Tembladero and Moro Cojo to represent alternate flood pathways that became apparent during the December 2014 flood.

Incorporation of MLML data – Hydraulic structure data was provided by Ross Clark, Charlie Endris, that was used to develop preliminary geometry for hydraulic structures located in the expanded portions of the model including:

1. Cabrillo Hwy crossing over Moro Cojo Slough
2. Moss Landing Rd tide gates at Moro Cojo

Other minor structure crossings in the model area were not accounted for due to lack of data. One improvement to the model would be to survey these crossings and add them into the model geometry to improve the representation of flow routing in the system.

3.1.2 Model Hydrology Inputs

Future flows determined in the future Q_{100} climate analysis were simulated by scaling the existing unsteady 100-year hydrographs that came with the HEC-RAS model provided by Monterey County. Base flow was maintained for the input hydrographs by only scaling the peak of each input hydrograph (flows > ~75% of the existing peak discharge). Within each hydrograph peak, a polynomial scaling function was used to produce smooth transitions between the existing rising and falling limbs and the future hydrograph peaks.

Inflow hydrographs were developed for Moro Cojo Slough and the unnamed canals/historic slough watershed. Area was determined for each watershed using USGS streamstats online tools. Then hydrographs were scaled from nearby subwatersheds analyzed by Schaff and Wheeler that possessed similar attributes (drainage area, relief, and impervious percentage) using watershed area as the scaling factor. These were scaled for future conditions using the method described above.

The downstream boundary was driven by an unsteady tide as described in the extreme coastal tide level section for the Reclamation Ditch.

3.1.3 Model Validation

The results of the updated hydraulic model run with the existing conditions 100-year hydrology and MHHW tailwater were compared to flooding extent and hydraulic flowpaths from a flood event that occurred in December 2014. The MLML provided a map of estimated extents and observed flow directions during this event. One key observation for this event was that flow backing up at the Moss Landing tide gates overtopped adjacent farm fields contributing additional water into Moro Cojo Slough which routes water to the harbor through the culverts under Moss Landing Road. The model reproduced this observed pattern for the 100-year flow as shown in Figure 9.

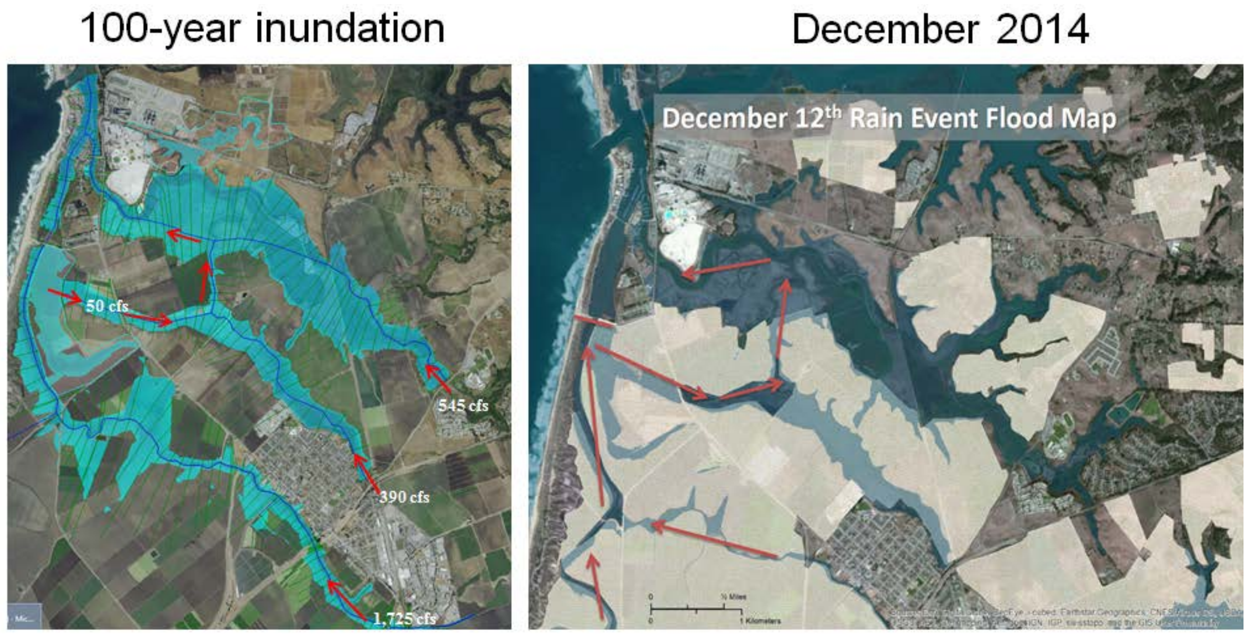

Figure 9. Comparison of Modeled 100-year flowpaths and observed flowpaths during December 2014 flood

3.1.4 Model Limitations

Flood mapping was truncated for Tembladero Slough at the Cabrillo Hwy, Moro Cojo up to the Railroad, and the historic slough in between. From the Tembladero up to the City of Salinas, the cross sections are limited to in channel portions, and floodplains were not mapped for any of the model coverage upstream. Given the uncertainty regarding the location of cross-sections an improvement to the model would be collecting new channel cross-sections and channel bathymetry in the model domain. Additionally, replacing the overbank areas with 2D flow elements would improve the routing of flow once it escapes the channel and goes out of bank. Lastly, the main Salinas River channel is not represented in the model. There are known interactions with the Salinas River and the Reclamation Ditch system including breakout flows from upstream entering the Reclamation Ditch and a water control structure connection between the mouth of the Salinas River and the old Salinas River alignment. The model could be improved significantly by combining the model with a model of the Salinas River and replacing the overbank areas with 2D flow elements.

3.2 Soquel Creek Steady State Modeling

3.2.1 Model Geometry Development

Hydraulic Roughness – The manning's n values were adopted from the existing FEMA model to maintain consistency. The channel and floodplain n values are 0.1 and 0.4 respectively.

Georeferencing – The existing conditions model for Soquel Creek came from the effective FEMA model for the system which was provided by FEMA as HEC-2 data-the precursor to HEC-RAS. The model was converted to HEC-RAS and georeferencing was performed to geospatially orient the model cross-sections and flood results. The georeferencing was accomplished by digitizing the length of Soquel Creek from the Pacific Ocean upstream to the limit of existing model coverage with HEC-GeoRAS tools in ArcGIS. Once the new stream centerline was imported to HEC-RAS, cross section spacing was adjusted to align bridge crossings with the known locations determined by the Terrain or aerial imagery. The model cross-section layout is shown in Figure 10.

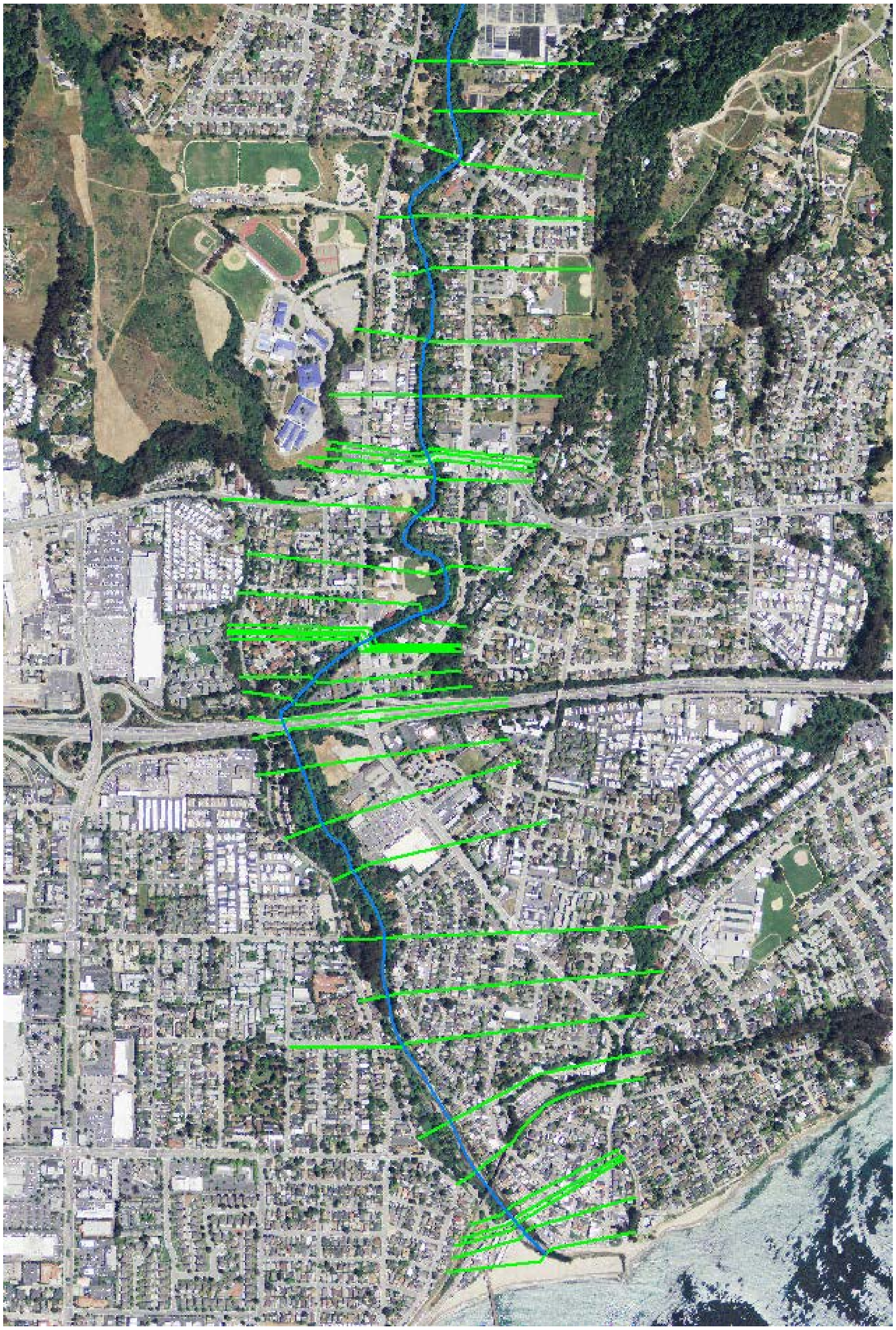

Figure 10. Soquel Creek hydraulic model layout

Update with LiDAR – Channel cross sections were extended to include the full floodplain and the cross section station-elevation data was updated with topography from the 2009 - 2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM (downloaded here: http://coast.noaa.gov/dataviewer/). This was only done for cross sections downstream of Soquel Nursery Growers Plant Nursery. In-channel bathymetry and hydraulic structure data were maintained, and were shifted from NGVD29 to NAVD88 using the datum conversion factor from the FIS (+2.75 ft).

Incorporation of MLML data – Hydraulic structure data (stormdrains, manholes, etc.) were provided by Ross Clark, Charlie Endris, but were not used in the model. These data can (are going to) be used to update flood connectivity of previously mapped coastal flooding hazards (ESA 2014), and would serve to improve fluvial flood mapping from an unsteady model of Soquel Creek.

3.2.2 Model Hydrology Inputs

Future peak flows determined in the future Q_{100} climate analysis were modeled in steady state. Flows were increased by the percent change calculated for the medium and high emissions scenarios and the three future time horizons. The downstream boundary was driven by a steady tide as described in the extreme coastal tide level section for Soquel Creek.

3.2.3 Model Limitations

The geometry information in the model, including hydraulic structures and in-channel bathymetry, are out of date and may not be representative of current channel conditions. These should be updated to better represent the current conditions in Soquel Creek. Because the model is steady state, overbank flooding is potentially overestimated. Flooding extents could be improved by switching to an unsteady model.

4 MODEL RESULTS AND FLOOD HAZARD MAPPING

The hydraulic model results include water elevations in each cross-section which were translated into geospatial datasets of flood extent and depth for each of the scenarios modeled. This flood hazard mapping process was accomplished using the HEC-GeoRAS toolbar for ArcGIS which enables data transfer between GIS and HEC-RAS. Water surface profiles from the model results were exported to GIS and differenced against the underlying NOAA LiDAR topography to map flood extent. This topographic dataset does not include bathymetry below the water line thus flow depths in the channel are representative of depth above the water line at the time during which the LiDAR data were surveyed. Though some channel bathymetry for Tembladero Slough and the Reclamation Ditch was present in the original HEC-RAS model, no clear geospatial information was available for precisely locating these data. Thus the bathymetry from the cross-sections was not integrated into the topographic surface. The results of the inundation mapping are shown for the Reclamation Ditch system in Figure 11 and for Soquel Creek in Figure 12.

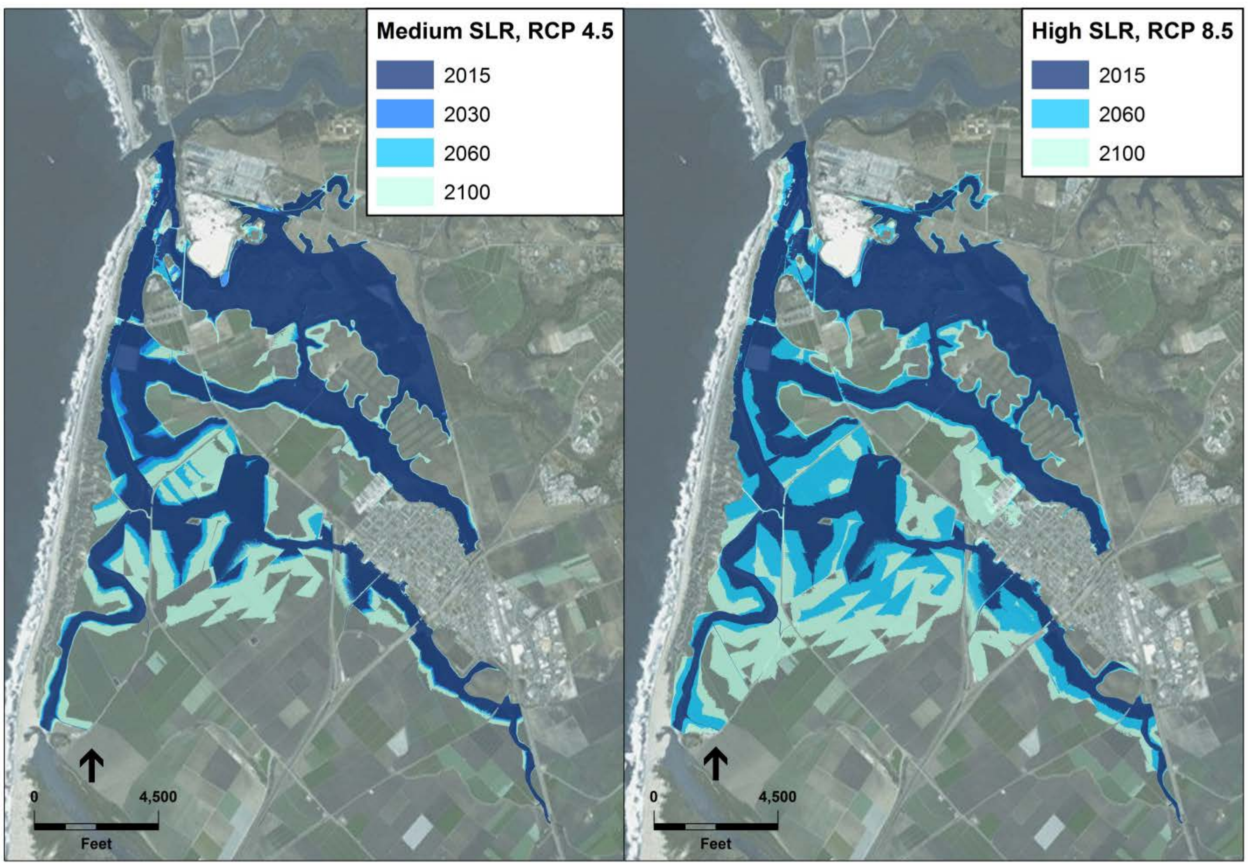

Figure 11. Flood inundation hazard maps for multiple climate scenarios on the Reclamation Ditch system

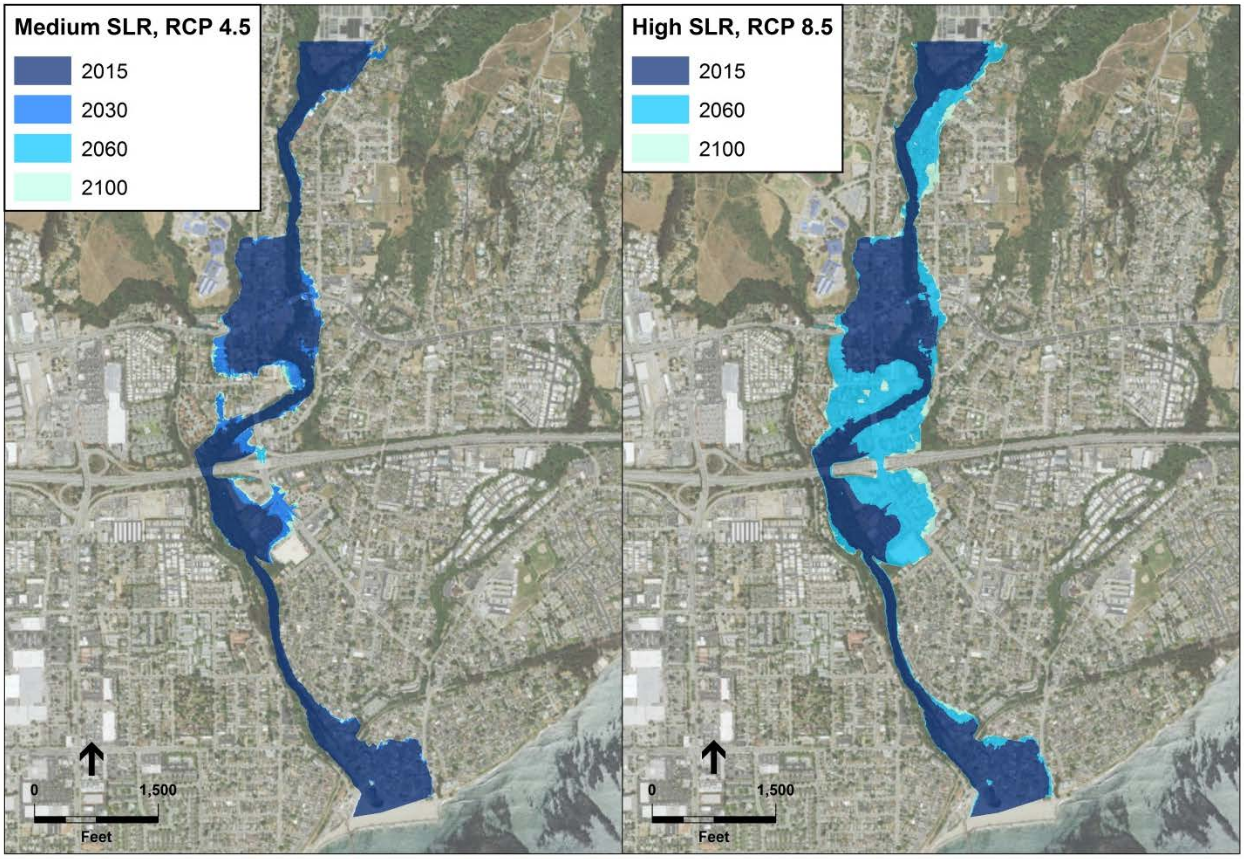

Figure 12. Flood inundation hazard maps for multiple climate scenarios on Soquel Creek

As Figure 11 shows, the flood extent increases significantly from existing conditions to 2100 on the Reclamation Ditch system. The majority of additional flooding is on the agricultural properties adjacent to Tembladero Slough and the Old Salinas River channel. The increase is exacerbated by the flatness of the terrain which results in a large increase in flooding for small increases in discharge. The additional flooded area is approximately 960 and 1740 acres for the Medium and High scenarios respectively, and the increase in flood depth is approximately 1.1 and 2.6 feet respectively. Depth measurements were sampled just upstream of the Hwy 156 crossings on Tembladero Slough.

For Soquel Creek, the change in 100-year discharge is less significant than on the Reclamation Ditch system. Additionally, the topography is more constrained in areas that are already flooded by the existing conditions 100-year flood. Thus the extent of flooding does not change as significantly on this system. The additional flooded area is approximately 18 and 65 acres for the Medium and High scenarios respectively, and the increase in flood depth is approximately 0.8 and 3.0 feet respectively.

In addition to the fluvial flood hazard mapping analysis, coastal storm flooding hazard zones were provided for the purposes of updating flooding connectivity in the Capitola and Salinas-Elkhorn areas. Coastal storm flooding hazards were previously mapped for the Monterey Bay Sea Level Rise Vulnerability Study (ESA PWA 2014) prepared for The Monterey Bay Sanctuary Foundation, and were provided in shapefile format for these two areas.

For the Capitola area (Soquel Creek), ESA provided MLML with intermediate coastal hazards shapefiles that contained separate polygons for the various hazards modeled. Equipped with the separated hazards and by using GIS data of storm drain networks and other flood management infrastructure, staff at MLML can make any warranted flood connectivity updates to the coastal flooding hazard layers provided in the MBSLR study (ESA PWA 2014). Described in the shapefile metadata, the separated versions of the coastal flooding hazards include layers for wave overtopping, wave runup, event tide flooding (100-yr tide), and erosion layers depicting eroded conditions of cliffs and dune areas (which would be considered as flooded in the future). Elevations associated with each flooding mechanism (except the erosion layers) are provided as attributes for each mechanism ("Method" in the attributes table).

As a part of a subsequent study "Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay" by ESA, The Nature Conservancy and others, flood connectivity was updated to reflect known water control structures in the area. The main structures considered are the tide gates on Tembladero Slough at Potrero Road, the Cabrillo Hwy road crest separating low lands from backwatering from the Moro Cojo Slough, and the water control structure between the Salinas Lagoon and Old Salinas channel to the north. In this update, flooding methods and associated flooding elevations for the Salinas River were altered to produce more accurate flood extents:

- Beach berm flooding – the elevation of flooding behind the beach berm at the Salinas River lagoon mouth was lowered from 4.88 m NAVD to 3.66 m NAVD (from 16ft to 12 ft) to represent the hydraulic control structure that diverts water north to the old Salinas River channel. These flooding layers also assume a 15 ft crest elevation for the levee on the north bank of the Salinas River, estimated from LiDAR.

- 100-yr tide flooding – flooding by the 100-year tide was updated to reflect the Potrero Rd tide gates and the road crest at Cabrillo Hwy, which affects primarily farmlands south of the Elkhorn Slough mouth.

The geospatial layers for the flood hazard extent and depths were compiled in an ESRI ArcGIS compatible geodatabase. The geodatabase was provided to MLML on 1/29/2016. Additionally the coastal flooding shapefiles adjusted to incorporate structural information on both systems was provided with this geodatabase. A table of the layers provided is included in Attachment A.

5 DISCUSSION

The climate analysis and hydraulic modeling show how future conditions flooding can change with increased precipitation intensity and higher coastal water levels with extreme coastal flood events. The flood hazard inundation extents can be used to inform planning efforts in the areas that are at risk of increased flooding as climate change puts added pressure on flood parameters. The range of scenarios provided allows for interpretation of potential flood risk given uncertainty in how climate will evolve. Planning efforts can be informed by considering a range of future scenarios and associated vulnerabilities, and the community's tolerance for risk, which should conceptually relate to the community's resilience.

The fluvial flood hazard maps add value to the previous coastal flooding analyses conducted by ESA by incorporating changes to watershed hydrology into the flood potential. This enables an assessment of the flood risk from combined changes in increasing coastal water levels and increased precipitation intensity. This is beneficial to communities at risk of flooding from both coastal and fluvial sources and provides a more complete set of scenarios for planning in those communities.

The resulting hazard maps can be used to assess risk as well as plan for future adaptation measures. By highlighting areas at risk currently and areas potentially at risk under different climate scenarios, communities can begin to develop and implement specific localized measures for adapting to these future risks. Future study should be considered to develop adaptation plans now that the tools for assessing risk have been developed and are available for further use.

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Monterey Bay Sea Level Rise

Climate Change Impacts on Combined Fluvial and Coastal Hazards

ATTACHMENT A

GIS Data Layers Provided With Report

Attachment A - Files transmitted via 20150126_fluvialHZ_w_Metadata.zip

Folder	Subfolder	File	Geographic Location	Type	SLR	Emissions
RecDitch_Tembladero_UTMz10						
	area					
		river100yr_floodplain_ec2010.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	none	none
		river100yr_floodplain_hi2060.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_hi2100.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_med2030.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2060.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2100.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
	depth					
		MaxDepth_100yr_ec2010.tif	Tembladero Slough	Fluvial flooding max depth raster	none	none
		MaxDepth_100yr_hi2060.tif	Tembladero Slough	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_hi2100.tif	Tembladero Slough	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_med2030.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2060.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2100.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
SoquelCreek_UTMz10						
	area					
		river100yr_floodplain_ec2010.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	none	none
		river100yr_floodplain_hi2060.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_hi2100.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_med2030.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2060.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2100.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
	depth					
		MaxDepth_100yr_ec2010.tif	Soquel Creek	Fluvial flooding max depth raster	none	none
		MaxDepth_100yr_hi2060.tif	Soquel Creek	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_hi2100.tif	Soquel Creek	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_med2030.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2060.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2100.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5

Key

SLR	High	high sea level rise (NRC 2012) of 159 cm by 2100, relative to 2010
	Med	medium sea level rise (NRC 2012) of 72 cm by 2100, relative to 2010
Emissions	RCP 8.5	future emissions scenario (IPCC, AR 5)
	RCP 4.5	future emissions scenario (IPCC, AR 5)

100-year fluvial flooding rasters and polygons are projected to UTM Zone 10N coordinates. Raster depths are in Feet.

Attachment A - Files transmitted via 20150129_Draft_UpdatedCoastalFloodHZ

Folder	File	Geographic Location	Type	SLR
coastal_storm_flood_MBSLR_Capitola				
subfolder "combined"	coastal_floodhz_ec2010_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	none
	coastal_floodhz_s12030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s12060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s12100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s22030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s22060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s22100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s32030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
	coastal_floodhz_s32060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
	coastal_floodhz_s32100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
subfolder "separated"	coastal_floodhz_ec2010.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	none
	coastal_floodhz_s12030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s12060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s12100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s22030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s22060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s22100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s32030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	coastal_floodhz_s32060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	coastal_floodhz_s32100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
event_flood_SMB_SalinasElkhorn				
subfolder "combined"	event_flood_AER_ec2010.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	none
	event_flood_AER_s22030.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	Medium
	event_flood_AER_s22060.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	Medium
	event_flood_AER_s22100.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	Medium
	event_flood_AER_s32030.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	High
	event_flood_AER_s32060.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	High
	event_flood_AER_s32100.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents	High
subfolder "separated"	event_flood_AER_ec2010_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	none
	event_flood_AER_s22030_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s22060_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s22100_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s32030_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	event_flood_AER_s32060_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	event_flood_AER_s32100_EL.shp	Salinas River / Elkhorn Slou	Coastal Storm flooding extents, with separate EL and HZ type attributes	High

Key

SLR	low sea level rise (NRC 2012) of 22 cm by 2100, relative to 2010
	medium sea level rise (NRC 2012) of 72 cm by 2100, relative to 2010
	high sea level rise (NRC 2012) of 159 cm by 2100, relative to 2010

coastal storm flooding rasters and polygons are projected to UTM Zone 10N coordinates